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In Vol. IV, p. 292, last line of Table 3, *for* 684 *read* 885; p. 295, line 12 of text, *for* 180 t. *read* 20 t.

SOIL PROBLEMS OF THE ANGLO-EGYPTIAN SUDAN

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WITH PLATE I

I. *Climatic Zones*

THE Anglo-Egyptian Sudan is nearly a million square miles in area. The northern half of the country is mainly desert; the southern half can produce crops but is unhealthy and difficult of access. The mean annual temperature varies between 25° and 27° C.; rainfall increases towards the south.

The railway system, which connects Khartoum, the administrative centre, with Egypt and the Red Sea, also taps the fringe of the rain-belt. This fringe has an annual rainfall of less than 400 mm. It contains three cotton-growing districts: the Gezira plain, of which part is irrigated from the Sennar dam, and the alluvial fans of the Gash and Baraka rivers, which permit flood-irrigation during their brief summer spate. Long-staple cotton is a recent introduction; the natural vegetation of this zone is short grass and sparse thorn scrub. The provision of water for cotton has facilitated the watering of stock, which was formerly a laborious business carried out by means of wells about 60 ft. deep. The natives are accustomed to raise quickly-maturing grain crops. In years of favourable rain these gave a good return for little labour, but this was small compensation for the danger of famine when the rains failed.

Farther to the south, a belt of land about 900 miles from east to west and about 200 miles from north to south receives summer rain, from 400 to 800 mm. a year, the winter months being rainless. The western part is occupied by cattle-owning Arabs and is traversed by Nigerian pilgrims on their way to or from Mecca. There is, however, neither rail nor river transport.

Towards the centre of this belt are the Nuba Mountains, inhabited by black pagan tribes. G. F. March [1] has given a valuable account of this region, which has better transport facilities, being situated in an angle between the railway and the White Nile. The eastern stretch, inhabited by nomad Arabs, contains much fertile soil, abandoned for lack of drinking-water. It is hoped that part of this area will be made habitable by provision of a drinking-water canal.

South of this belt is the country of the negro tribes, Shilluk, Dinka, Nuer, and many others. They inhabit a roughly triangular area of about 150,000 square miles bisected by the White Nile, which is the main channel of communication between Khartoum and the south. The annual rainfall in this region is between 800 and 1,200 mm., of which the greater part occurs during the summer. As a whole, the area is sparsely populated. Its western part is intersected by tributaries of the White Nile; in the centre are vast papyrus swamps which will eventually be drained in the interest of water-conservation, and to the east there is a region of grey clay soil and elephant grass.

At the south and south-eastern border of the Sudan the East African Plateau is approached. Along the Nile–Congo watershed, the annual rainfall exceeds 1,200 mm., and the soil is mainly red. The red-soil area covers about 30,000 square miles, and parts are known to be very fertile. At the moment the population, mainly Azande, is small and apparently stationary, and imposes a limit on immediate development. Sleeping sickness is endemic near Tambura, but progress has been made towards its control. Transport is a further difficulty but not an insuperable one, and investigations are now being directed to the choice of suitable crops.

II. *Conditions Determining Soil Research in the Sudan*

As would be expected from the foregoing account, the Sudan Government devotes a large proportion of its revenue to medical, agricultural, and veterinary services. The Agricultural Department includes a research organization of which one section is concerned with direct study of the soil.

The soil of the Sudan is almost its only material asset. There are no important mineral resources. Soil and climate determine crop-production, upon which depend the revenue of the railways, which are state owned, and the health of the people and of their animals. Tax-collection, land-tenure, and the adjustment of grazing rights are familiar problems also depending on soil and climate. Whereas variations in climate are neither cumulative nor controllable, variations in the use made of land are subject to control and can have an overwhelming cumulative effect.

It is common knowledge that misuse of land can produce in a few years damage which may take ten times as long to remedy, if, indeed, it can be remedied at all. For this reason the farmer, in countries of long-established agriculture, is forced to comply with regulations designed to protect his neighbours and successors from injury. In tropical lands, however, there is practically no traditional knowledge as to what constitutes misuse of land, and accordingly the most urgent task of the soil investigator in the tropics is to detect, measure, and control any changes in the soil which occur under native management, or which result from the introduction of methods of cultivation that are new to the country. A direct inference from this general statement is that no single examination of the soil, however thorough, can provide reliable information as to change occurring through a period of time. At least two and, preferably, a series of observations should be made.

Another important consideration is that in countries where the seasonal variation in climate is great, there is likely to be considerable seasonal variation in the moisture-content, nitrogen status, physical condition, and other properties of the soil. Such changes may be described as 'soil rhythm'; they occur both in cultivated land and in land bearing its natural vegetation. In broad outline, therefore, the task of the soil investigator in the tropics is to assess the effect on the natural sequence of changes in soil through time of introducing new crops and new methods of cultivation. The disturbance imposed on the natural sequence

is not necessarily harmful, but, on the whole, study of these natural changes is desirable in order that the agricultural pioneer may knowingly utilize, rather than unconsciously defy, powerful factors which are, to some degree, beyond control.

In the Sudan, therefore, investigation of the soil demands, in the first place, the patient, long-continued, and repeated examination of not very dissimilar materials. To achieve this aim through the agency of highly trained personnel on short-term contracts would be costly and difficult. On the other hand, research officers on long-term contracts will find it to their own interest to devote their first years in the country to training a staff of native assistants to undertake duties of gradually increasing complexity. The information most urgently required is precisely that which best facilitates such training, and it is a pleasure to record that, in my experience, the natives derive a genuine intellectual satisfaction from their work, and appreciate its bearing on the agricultural prosperity of their country.

To guard against misunderstanding it should be added that in all branches of the Government service attempts are being made to extend the work and responsibility of native staff. This policy is no monopoly of the soil-research section but is mentioned here as determining the order in which soil problems are best attacked.

While the necessary basic information is being collected, and while the training of native staff is in progress, it becomes clear that some topics are less important than they first seemed, whereas others are found to require very thorough investigation. It is at this stage that a well-trained staff can be of great help by accurately carrying out tasks which would otherwise consume the time of the senior workers. There is, however, an additional reason for building up an efficient native staff, namely, the inevitable demand for information about the soil in areas hitherto untouched.

It has been shown that in the Sudan about 400,000 square miles of country may eventually become available for agricultural development. To obtain, in the course of a century, reliable data about this area may be regarded as a reasonable objective. It involves on the average the examination of 4,000 square miles per year, but a much slower rate of work is permissible during the earlier decades. In point of fact, it is now proposed to study the red-soil region near the southern border of the Sudan. We shall evidently require both to ascertain with moderate accuracy the geographical distribution of soil types, and also to obtain the necessary basic information concerning the natural and imposed changes to which the soil is subject. As the staff of the soil-research section consisted in 1935 of two British chemists and about a dozen partly trained native assistants, it will be understood that considerable expansion is envisaged. The cost of the work can be kept within reasonable bounds only by training native assistants. Apart from cost, however, it seems appropriate that the natives of the Sudan should, in this way, take an important share in developing the country. The task is complex, but may form a bond between tribes which 'no ancient history or common tradition unites'.

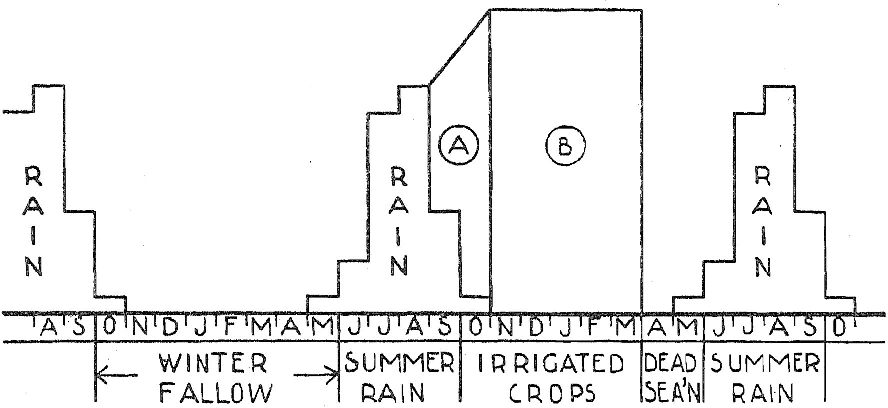
III. *Soil Problems of the Gezira*

Since 1906 the staff of the Wellcome Tropical Research Laboratories, and since 1931 the staff of the Agricultural Research Service, have devoted much attention to problems associated with irrigation of the eastern Gezira. Under the direction of A. F. Joseph, Government Chemist 1919–31, a soil survey of the area was completed, the chemical and physical properties of the soil were studied, cotton yields were related to local differences in soil profile, and the possible ill effects of irrigation were reviewed. Provision was made for long-period observations of certain field characteristics of the soil.

The soil [2] is a heavy clay, salty, alkaline, of low permeability, and low in content of nitrogen and organic matter. When sown to cotton it responds to early application of nitrogenous manures, but not to potassium, phosphorus, and minor elements. The short summer rains, of which two-thirds fall during July and August, permit growth of grasses and sorghum. The rains are followed by a long period of bare fallow during which the soil dries and becomes extensively cracked. Wind and rain carry surface material down these cracks, thus setting up a process of soil circulation which is confined to the top two or four feet of soil. The natural soil rhythm of the region thus consists of a brief period of biological activity, followed by fissuring and exposure of the soil mass. The rate of water-loss from soil decreases with depth; at a depth of two or three feet the soil retains throughout the year sufficient moisture to saturate any air present in the interstices. Plant-roots are for the most part confined to the comparatively shallow zone of soil in which these seasonal changes occur. The soil normally contains little salt, but sulphates of sodium and calcium are usually present in the subsoil.

Irrigation affects the soil both by prolonging the period of biological activity and, of course, by curtailing the fallow, and also by bringing on to the land salts contained in the water of the Blue Nile. Observations, extending over some years, showed that with normal use of irrigation-water, subsoil salts did not rise into the root-zone and there impede growth; they seemed, on the contrary, to be slightly depressed. Sulphates applied in solid form at the soil surface are washed into the subsoil, and this appears to apply also to the salts contained in the irrigation water. We have failed to wash salts to considerable depths after moderate applications of gypsum and other soil improvers, and more drastic experiments are now in progress. Chemical transformation of the soil is evidently difficult and costly; it is, perhaps, undesirable. There seems small prospect of establishing drainage in absence of soil improvers, because the soil rarely contains any gravitational water, except immediately after irrigation and in direct proximity to the soil surface. Effluents of considerable volume have, however, been obtained from drains laid in channels filled with coarse sand to within a few inches of the soil surface. It is possible that undisturbed soil adjoining these channels will be improved chemically by giving up some of its sodium to the water. The extent of this change should not be a matter for conjecture but, unfortunately, the problem of base-exchange between a mineral

colloid and a very dilute salt solution has, at present, no secure theoretical basis. It has recently been established [3] that the course of base-exchange depends on the ratio of soil to solution, and it is hoped that further work along these lines may clear up some of the difficulties. The irrigation-water is of good quality in that dissolved solids are low and calcium predominates over sodium. In addition, Gezira soil shows preferential absorption of calcium as against sodium and, conversely, readily yields sodium by hydrolysis. It is possible therefore that, in respect of its exchangeable bases, Gezira soil will be improved by irrigation. Some years must pass before we have adequate information on



this point; meantime, it is satisfactory to note that in regard to exchangeable bases, three areas, which have long been irrigated, have been found to compare favourably with two areas recently irrigated.

In spite of what has been said in the preceding paragraph, the possibility that, in absence of drainage, soil deterioration may result from the continued introduction of salts, remains the most important problem that we have to face. It is clear, however, that deterioration is, at least, slow, and accordingly we may profitably consider how best to use the soil in its present state. For this purpose each agricultural operation, such as the raising of a crop by means of irrigation, may be regarded as a disturbance of the natural soil rhythm. One obvious result of irrigation is that soil is kept moist for a longer period than is usual under natural conditions. The accompanying diagram provides a rough measure of the normal rainfall (G. R. F. Medani, 1919–33), of the additional water, A, given to crops of sorghum or dolichos lablab, and of the additional water, A+B, given to Egyptian cotton. It will be noticed that the grain and leguminous crops involve a slight prolongation of the natural period of biological activity, whereas the cotton crop occupies the land so long that the normal winter fallow is reduced to a short 'dead season' immediately preceding the early rains. When early rains are heavier than usual there is, of course, a greater risk that insect pests will be able to survive the 'dead season'. On the other hand, insects doubtless shelter in the deep cracks of the soil, so that cessation of watering is not a perfect means of control.

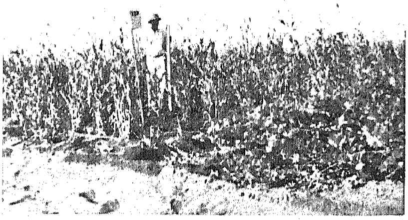
The six photographs reproduced in Plate I show growth of sorghum in the autumn of 1935 on representative sub-plots of a rotation experiment. The sorghum was sown in early July. During the preceding winter the land had been fallow in sub-plots 30, 148, and 143, and had been under cotton in sub-plots 137, 79, and 106. The man, about 6 ft. tall, who is clearly seen in the left-hand photographs, is barely visible in the others, owing to the superior growth of sorghum after fallow. Dolichos lablab is seen in the foreground of sub-plots 137 and 148. On the assumption that sorghum stalks contain 1 per cent. and sorghum heads 2 per cent. nitrogen, the harvest, expressed in lb. nitrogen per acre, was as follows:

Rotation								*Courses*	*Lb. N. per acre*	*Representative sub-plot*
				C	L	C	S	4	55	No. 137
		F	C	L	F	C	S	6	39	No. 79
F	F	C	L	F	F	C	S	8	57	No. 106
		C	F	L	C	F	S	6	110	No. 30
F	C	F	L	F	C	F	S	8	73	No. 148
C	F	F	L	C	F	F	S	8	111	No. 143

(Note: C = cotton; F = fallow; L = dolichos lablab; S = sorghum. The experiment began in season 1931–2 at the point marked by a double line.)

It is evident therefore that, if growth of the sorghum be taken as an index of soil fertility, a preceding cotton crop harmfully disturbs the normal sequence of changes in the soil, whereas an intervening long winter fallow allows the natural sequence to be resumed. It has been established also that growth of cotton is better after a long winter fallow than after sorghum and a curtailed fallow, so that, if growth of cotton be taken as index of soil fertility, sorghum causes a harmful disturbance of the soil rhythm. A leguminous crop, on the other hand, has a beneficial effect. Thus the rotation, cotton—sorghum—dolichos lablab, is superior to the rotation, cotton—sorghum—fallow.

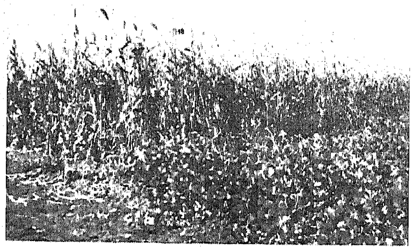
To ascertain precisely what changes occur in the soil under different methods of management necessitates the long-continued observation of a series of plots. One would, for example, wish to compare changes in continuously fallow land with those in cotton—fallow, in cotton—fallow—fallow, and in other rotations including continuous cotton. These observations of soil rhythm are analogous to tidal measurements, with the difference that their period may be several years instead of twelve hours. In the comparison of five 3-course rotations we have records of the nitrate-content of top-foot soil over a period of nine years; a more elaborate method of nitrogen analysis has been in operation for about three years; and observations on the physical condition and alkalinity of these plots cover about the same period. The work now includes the examination both of top-foot and of second-foot samples. Systematic records of soil carbon will shortly be added, but there is no immediate prospect of including direct studies of soil micro-organisms. No attempt



Plot 137

Plot 30

Plot 79



Plot 148

Plot 106

Plot 143

has yet been made to assess seasonal variations in carbon-dioxide content of the soil or in availability of phosphate.

Among the results obtained in the course of this work are the following. Irrigation causes deterioration in the physical condition of soil, and this is remedied by fallowing. There seems to be no adverse cumulative change in this respect. The rains initiate activity of micro-organisms in the soil; excessive rain or irrigation during early growth of a crop sets up anaerobic conditions, which are undesirable. When the rains cease, micro-organisms become dormant in top-foot fallow soil. In some winters top-foot fallow soil has a low nitrate-content, in other winters, a higher content; in either case, the level is maintained until the onset of the rains and is unaffected by insolation. Sorghum rapidly takes up nitrate from the soil; its effect on total nitrogen is not yet clear. A leguminous crop increases soil nitrogen, but the effect on nitrates is not marked during growth or soon after harvesting. There is a marked absence of relation between seasonal variations in growth of cotton and the nitrate-content of soil. This supports the view that damage to cotton roots by soil fungi is an important seasonal factor. We await further information as to the conditions under which damage is severe.

It will be realized that, although one may confidently expect results of immediate practical importance from the continuation of these long-period investigations, it should be possible in some cases to confirm or anticipate them by means of laboratory experiments. Researches of this kind require the uninterrupted attention of the senior staff and are often crowded out of the programme. It is hoped, however, that this difficulty will become less as the junior staff gain experience in their work. The general low level of nitrogen and of carbon in our soils is, no doubt, the product of those natural changes which have been described as soil rhythm, but is not necessarily the best that can be expected. On the contrary, to improve soil in these respects is an obvious subject for laboratory investigation. Some work of this kind has been carried out, but there remains a wide and promising field for study.

Little progress has been made in relating irrigation-practice to meteorological conditions. On the one hand, water-duty experiments are difficult and have not given very striking results, and, on the other hand, the death of R. H. K. Peto interrupted our study of the way in which energy of solar radiation is used when incident on irrigated soil. It is hoped that this rather obvious group of problems will not continue to escape investigation.

Two striking features of cotton cultivation in the Gezira are the seasonal fluctuation in yield and the fairly consistent results obtained in date-of-sowing experiments. The former has been ably investigated by E. M. and F. Crowther [4], who find that the variations in yield are closely correlated with variations in rainfall. Rains affect weed-growth, agricultural operations, the spread of insect pests and of Black Arm, a bacterial disease; they have in addition direct effects on the soil, which are partly elucidated by the observations mentioned above. The outcome of these seasonal factors is usually a well-marked optimum period for sowing cotton, but this depends not only on the soil but on atmospheric

conditions which become rapidly more severe during September and October. Late sowings give little or no response to nitrogenous manures.

It has become increasingly evident that the early growth of the crop is of decisive importance in determining the final yield. How far variations in growth depend on conditions in the soil is not yet known. On the one hand, the main seasonal effect is pervasive, whereas it would be expected that, owing to local irregularities of rainfall, certain fields would give exceptional yields. On the other hand, experimental plots, supervised with great care, sometimes show a marked local variation in fertility which seems unconnected with the more permanent features of the soil, and is probably the result of local differences in soil moisture at some critical period.

IV. *Other Soil Problems of the Sudan*

The deltas of the Gash and Baraka rivers are relied upon to produce Egyptian cotton of excellent quality so long as attention is paid to the control of flood waters, to the eradication of weeds, and to control of seed. The soil is ideal and likely to remain so. In the Nuba Mountains development will continue to rest on the sympathetic supervision and instruction of small-holders and on the provision of seed and markets. The natives have some experience in the management of their soils, and probably do not need such information as may be obtained from organized research. On the other hand, as this area is within easy reach, it should not be difficult to study any soil problems that may arise. The extension of soil survey in this direction may be regarded as a continuation of work now in hand.

There are, however, two or three major problems demanding close technical co-operation, which we have yet to tackle. They are the development of the red-soil region in the southern Sudan, the control of soil erosion along the fringe of the rain-belt, and the draining of the Sudd, the vast papyrus swamp in which much of the White Nile water is lost by evaporation.

Development in the Southern Sudan.—It is said that emigration projects never succeed unless the area chosen consists of excellent soil. The development of the sparsely populated southern Sudan is sufficiently akin to emigration for the quality of the soil to be of paramount importance. Where difficulties of transport, health, and administration are acute, it is imperative to ensure that the soil, chosen for an enterprise, is uniformly excellent and that the method of cultivation is appropriate. Among the dangers to be guarded against are the following: damage by natives who carelessly set fire to vegetation in order to clear land or drive game; damage by erosion following removal of natural vegetation without providing a cover crop or terraces; damage by improvident exploitation of areas in which a self-supporting natural vegetation is replaced by a commercial crop making heavy demands on slender mineral reserves; damage by exposure of soil, resulting in rapid consumption of its organic matter; and damage by deforestation, resulting in extensive changes in soil moisture. The positive aims of a land-utilization survey have been ably summarized by C. E. Kellogg and J. K. Ableiter [5],

who urge that land classification should be based on strictly pedological principles, and that the survey should be sufficiently detailed to be directly applicable to holdings of normal size. By normal size is meant normal for a region in which some use, such as cropping, grazing, forestry, or recreation, is made appropriate by its special features of climate, soil, topography, and accessibility to markets. These physical features of the land affect or determine the size of the individual holding, the general agricultural character of the region, and the system of land tenure which is best suited to it. The object of soil survey therefore is to obtain and record adequate data about these physical features of the land. In the present case the survey will presumably begin in the more accessible areas which promise a return for intensive development, and will gradually be extended. Elsewhere a reconnaissance-survey is the most that can be attempted in the near future.

Soil Erosion.—Practically no information is available in the Sudan on the occurrence of soil erosion along the fringe of the rain-belt. In this region vegetation is sparse and gives little protection in years of heavy rainfall. Erosion may result either from destruction of terraces in land abandoned through famine, war, pestilence, or failure of the water-supply, or from over-grazing occasioned by cessation of tribal warfare, by improved water-supplies, and by provision of medical and veterinary services. Soil erosion is to be expected owing to the torrential character of the brief rains which beat down upon unprotected soil; that soil erosion occurs is shown by the high silt-content of flood waters in such regions. To ascertain the extent of soil erosion now occurring in the Sudan and to devise means of control is an urgent practical responsibility to be faced by the Government. Fortunately, the menace of soil erosion is now so widely recognized that it should be possible to secure the co-operation of the administrative and various technical services in an effective attack on this problem. There is evidently scope for aerial reconnaissance which, if checked by ground surveys, should greatly expedite the work.

Drainage of the Sudd Region.—The Egyptian Irrigation Department has for many years been engaged on the task of providing permanent channels for White Nile waters through the Sudd region. The object of this work is to conserve the large volume of water which is at present lost by evaporation in this swamp. From the soil point of view this project involves a partial reclamation of the area somewhat resembling the draining of the Hungarian plain. Such reclamation will provide problems for another generation of pedologists.

Summary

Although the northern half of the Sudan is desert, the southern half, about 400,000 square miles in extent, may be capable of bearing crops. During the past 30 years only a very small fraction of this area has been the subject of detailed soil investigations, but the work can be made to keep pace with improvements in health and transport. To extend soil research at reasonable cost it is necessary to employ native assistants. These men can be trained in the course of the long-period observations which are needed to determine the effects (*a*) of seasonal variation in

climate, and (*b*) of cultivation on the moisture-content, nitrogen status, and other properties of the soil. Such changes in the soil with time may be described as soil rhythm, just as changes with depth are described as soil profile. Owing to the lack of traditional knowledge of tropical soils, the study of soil rhythm is of great importance.

In the Sudan Gezira no cumulative deterioration of the soil has been detected as a consequence of irrigation, and investigations are accordingly directed to making the best use of the soil in its present condition and to improving it.

A start is being made with a direct study of the soil in the southern Sudan, where about 30,000 square miles of country await development. Another task to be attempted as soon as possible is the control of soil erosion along the fringe of the rain-belt. At present we lack information on this subject which may prove to be of urgent importance. A more distant pedological objective is the reclamation of the Sudd region of the White Nile.

Acknowledgements

I have to thank Messrs. M. A. Bailey, G. J. Flemming, E. Mackinnon, G. F. March, and E. D. Pridie for suggestions which I have included in this note. The quotation at the end of section II is from Sir Harold MacMichael's book, *The Anglo-Egyptian Sudan*.

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THE PHOSPHATE STATUS OF MAURITIUS SOILS

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In any discussion on the phosphate status of soils, not only must the total amount of phosphorus be considered, but also the form, or forms, in which this element occurs. It is possible that a soil may contain a fairly high amount of phosphoric acid soluble in concentrated hydrochloric acid, and yet, owing to the conditions prevailing in the soil, there may be an insufficiency of readily available phosphate for optimum plant-growth.

Various methods may be employed to determine whether the soil contains sufficient available phosphorus, and of these the best known are Dyer's 1 per cent. citric-acid method, Truog's 0·002N sulphuric-acid method [1], and Winogradsky's azotobacter test. The fixation of soluble phosphate added to the soil may also be investigated by the test of Demolon and Barbier [2]. Results obtained by some of these methods supply certain information regarding the form in which the phosphates exist in the soil.

Organic phosphorus.—Phosphorus may occur in many different forms, each of which may supply this element to the crop in varying degrees. Part is undoubtedly in the form of organic compounds, as the soil always contains decaying organic matter of which phosphorus is an essential component. It seems not unlikely that this fraction must be converted into the inorganic form before it can be utilized by the plant. Consequently conditions favouring the destruction of organic matter probably tend to render the organic phosphorus available for plant-growth. This fraction probably becomes available fairly quickly in tropical soils, where conditions are, as a rule, suitable for the intense destruction of organic matter.

Inorganic phosphorus.—Inorganic phosphorus is chiefly present as phosphates of iron, aluminium, or calcium, the relative amounts of which may vary greatly in the different soil types. Although the availability of the various inorganic forms varies considerably, yet in none is the phosphorus absolutely of no value to the crop. It has been shown that the calcium phosphates are by far the most readily available, but it must be recognized that a soil containing phosphorus combined with iron or aluminium only may provide a sufficiency of available phosphate. This can only happen when a high reserve of phosphate has been created in the soil, and once this has been done, all that is required in the future are regular applications, sufficient to replace the losses incurred by the preceding crop. Thus a large quantity of iron or aluminium phosphate in the soil may have a similar effect upon the crop as has a much smaller quantity of calcium phosphate, with this important difference, that a definite phosphate fertility due to the former is more durable than one based on the latter. Phosphate-fixation by the sesquioxides is, therefore, not an unmitigated evil, as it prevents loss in drainage water, and it gradually raises the level of fertility. This is seen in Hawaii, where heavy

applications of phosphates have been made for some years to soils that were originally deficient [3]; at the present time it is possible to reduce the applications of phosphatic fertilizer without adversely affecting the crop. It seems probable that there is also at least one case in Mauritius where high soil fertility has been built up by continued applications of phosphatic fertilizers. Deep River S.E. and Olivia S.E. are in close proximity, in similar climatic conditions, with no topographical difference that might cause any marked soil differences [4]. The soils of the former estate are well supplied with phosphorus, both total and available, whilst those of the latter are highly deficient in the available forms. The only reasonable explanation of this difference lies in the past method of fertilizing. Incidentally, the yields at Deep River S.E. are on the average higher than those at Olivia S.E., and it seems probable that the difference in phosphate status is at least partly responsible.

Phosphate in Mauritius soils.—The phosphate status of the various soil types in Mauritius is indicated in Table 1, in which the different soils have been set out in five groups according to the amount of phosphoric oxide soluble in 1 per cent. citric acid.

TABLE 1. *The Distribution of Readily Available Phosphoric Acid (by Dyer's Method) in Five Different Soil Types in Mauritius*

Readily available P_2O_5, *parts per million*	*Mature soil, highly laterized. Brownish-yellow soils*		*Mature soil, intermediate degree of laterization. Yellowish-brown soils*		*Mature soil, low degree of laterization. Red soils*		*Immature soil, low degree of laterization. Dark-brown soils*		*Grey soil*	
	No. of samples	*Per cent.*	*No. of samples*	*Per cent.*	*No. of samples*	*Per cent.*	*No. of samples*	*Per cent.*	*No. of samples*	*Per cent.*
0–10	11	59	4	14	8	33	0	0	0	0
11–25	5	29	16	55	8	33	3	50	0	0
26–50	2*	12	8	28	5	21	1	17	0	0
51–100	0	0	1	3	1	4	2	33	0	0
Over 100	0	0	0	0	2	9	0	0	4	100

* These two soils were from Deep River S.E. whose pH values have been raised by systematic liming, and where a phosphate fertility has been built up by means of regular applications of phosphatic fertilizers.

These figures illustrate the variation which may be expected in the different types. In all the main types under sugar-cane cultivation; i.e. in all except the grey soils, there are considerable differences in content of available phosphorus, so that recognition of the soil type cannot be any guide to phosphate fertilization, except in the case of the highly laterized soils, which are almost invariably deficient. The dark-brown, immature soils of the dry districts are the cultivated soils which are best supplied. These results have been confirmed by further series of analyses not yet published. The grey soils, which are totally different from all other soils, are not as a rule under sugar-cane cultivation, but are covered with a natural savannah vegetation. They have probably been formed

under conditions of impeded drainage, with the result that they cannot be considered as lateritic soils, the molecular silica/alumina ratio of the clay-fraction being more than 3·0. All the grey soils so far examined have contained an abundant amount of available phosphoric oxide.

States of combination of phosphorus in Mauritius soils.—That phosphorus does occur differently combined in Mauritius soils is shown first of all by the varying ratios of available phosphoric oxide (Dyer's method) to phosphoric oxide soluble in concentrated hydrochloric acid. Thus, although the average contents of phosphoric oxide soluble in hydrochloric acid in both the highly laterized mature soils and the red soils from the dry regions are about the same, i.e. approximately 0·21, the amounts in the available form are very different, being 0·00096 per cent. for the former and 0·0029 per cent. for the latter. This indicates, therefore, that the phosphoric acid in the slightly laterized soils of the dry regions is in a more readily available condition than is that in the highly laterized soils of the high-rainfall districts. At the same time, exchangeable calcium is much more plentiful in the former than in the latter, so that it is reasonable to assume that there may be a higher proportion of calcium phosphate in these soils than in the highly laterized ones. Even in these soils, when the amount of exchangeable calcium has been artificially increased by the addition of liming materials, as at Deep River S.E., the proportion of available phosphoric acid is similar to that in the red soil.

Consequently the stable form in which phosphoric acid may exist in the soil may be profoundly affected by altering the pH value, and therefore the exchangeable-base status, a greater proportion of the phosphoric acid remaining available in the nearly neutral soils, rich in exchangeable bases, than in the more highly acid ones, which may be almost devoid of these bases. It does not necessarily follow that the liming of a soil will result in increased availability of the phosphorus pre-existing in the soil; indeed, it is possible that the reverse may happen. Liming may, however, have an important effect upon phosphoric acid applied subsequently as fertilizer in that a higher proportion may remain in the readily available form.

Availability of phosphorus in Mauritius soils.—The figures published in Bulletin No. 4 of the Sugar-cane Research Station show that the results obtained from Dyer's and Truog's methods are as a rule fairly similar. Average figures for three types showing the differences which might be expected are given in Table 2.

TABLE 2. *Comparison of the Amounts of Available Phosphoric Oxide by Dyer's and Truog's Methods*

	Available phosphoric oxide as percentage of dry soil		
	Average for red soils	*Average for highly laterized, mature soils*	*Average for highly laterized, immature soils*
Dyer's method . .	0·0029	0·00096	0·0030
Truog's method . .	0·0049	0·00074	0·0006

In dealing with mature soils, both methods are equally good for determining their phosphate requirements. The two methods show important differences with the highly laterized, immature soils, in that Dyer's method indicates that they are fairly well supplied with available phosphoric acid, whereas Truog's method shows that they are highly deficient.

Subsequent investigation showed that the sulphuric acid, as used in Truog's method, fails to extract any organic phosphorus, but it would appear to be more efficient than 1 per cent. citric acid for extracting inorganic phosphates, in view of the results obtained with the red soils. When the organic matter in the highly laterized soils is destroyed by treating with magnesium nitrate solution (free from phosphorus and arsenic), and subsequent gentle ignition, the amount of soluble phosphorus by Truog's method becomes practically the same as that by Dyer's method. It may be stated, therefore, that these highly laterized immature soils are well supplied with available phosphorus in organic combination. The fact that these soils are rich in organic matter (as much as 10 per cent.) indicates that conditions are not highly satisfactory for its decomposition, and consequently it may be that the organic phosphorus becomes mineralized somewhat slowly. Again, it seems probable that the major portion of the available phosphorus in the mature soils is present in the inorganic form.

It has already been pointed out that the inorganic phosphorus, in combination with both calcium and iron, is capable of being utilized by plants, but in varying degrees. Truog and Dean [5] suggest that the source of the readily available inorganic phosphorus may be indicated by using different soil/acid ratios for the extraction, the suggested ratios being 1 : 200, 1 : 400, and 1 : 800. When the calcium compound is the chief source of available phosphate, it is dissolved at the lowest ratio (except when the amount is excessive or when the soil is highly calcareous), and consequently when the higher ratios are employed there is only a slight increase in the total amount extracted. On the other hand, they consider that the solution of phosphoric oxide from basic iron phosphate is chiefly due to hydrolysis, and consequently, when this compound is the chief source, appreciably more phosphorus is extracted as the ratio of acid to soil is increased. This differentiation becomes important when there may or may not be a sufficiency of available phosphate for the growing crop. Thus, there may be two soils, each with the same amount of available phosphorus, in one of which calcium phosphate is the source of supply, and in the other basic iron phosphate. In this case the former is more likely to suffer from phosphate deficiency, as the large amount of the iron compound will be better able to maintain an available supply throughout the growing-season than the small quantity of calcium compound.

Eleven Mauritius soils have been examined for available phosphoric oxide by means of Truog and Dean's method, with the varying soil/acid ratios, and the results so obtained are given in Table 3, together with those for Miami silt loam and an Hawaiian clay, No. 4391. The Miami silt loam is a soil in which most of the available phosphoric acid is derived from calcium phosphate, whereas the Hawaiian clay is one in which the

chief source is basic iron phosphate. The figures show that the amount of available phosphoric acid in the Miami soil does not increase greatly as the volume of acid increases, but the increase is great for the Hawaiian soil.

TABLE 3. *Effect of Varying the Soil/Solvent Ratio on the Amount of Available Phosphoric Oxide Dissolved*

Soil no.	P_2O_5 *soluble in conc.* HCl. *% dry soil*	*Phosphoric oxide extracted by solvent at different ratios in p.p.m.*			pH	*Exchangeable calcium in m. eq. % dry soil*	*Org. matter % dry soil*	*Molecular ratio* SiO_2/R_2O_3
		1/200	1/400	1/800				
69	0·15	58	80	56	7·10	20·4	3·5	1·46
64	0·18	12	20	34	6·75	16·5	3·9	1·22
65	0·32	88	108	144	6·75	18·1	4·8	1·20
103	0·27	88	100	130	6·75	14·8	5·7	0·43
16	0·37	58	29	52	6·70	13·8	5·9	0·29
74	0·28	28	..	40	6·60	13·7	4·1	1·07
22	0·28	26	28	56	6·55	14·8	5·0	1·18
6	0·26	12	22	28	6·10	13·8	5·7	1·37
105	0·39	7	8	16	5·75	4·5	4·8	0·46
25	0·17	7	14	24	5·60	2·2	5·8	0·25
55	0·30	9	16	20	5·60	4·9	4·8	1·30
Miami silt loam	0·075	70	74	78	..	..	..	..
Hawaiian* clay 4391	1·35	85	140	210	..	..	..	..

* The results for Miami silt loam and Hawaiian clay 4391 are extracted from Truog and Dean's paper [5].

From the results quoted for the Mauritius soils it will be seen that, with the exception of soils 69 and 16, there is always a definite and progressive increase in the amount of phosphoric oxide extracted with the larger volume of acid. In the two exceptions there is one anomalous result, so that there is a certain amount of doubt respecting them. In general, however, it would appear that in the majority of soils examined, basic iron phosphate forms an important source of supply of available phosphoric oxide, but there is still the possibility that the soil contains a certain amount of calcium phosphate, especially in the soils with pH values approaching neutrality. In the table the soils have been arranged in order of descending pH values, and although the HCl-soluble P_2O_5 shows no correlation with pH, yet the soils with the higher pH values contain much more readily available phosphoric acid than do the soils with low pH values, and the ratio of available P_2O_5 to total P_2O_5 tends to decrease as the pH value decreases. The molecular SiO_2/R_2O_3 ratio, within the range usually encountered in lateritic soils, does not seem to have any great effect upon the availability of the phosphoric acid, judging from soils 103 and 16. Both of these are highly laterized soils in which the natural acidity has been reduced by regular applications of liming materials, and in which phosphate fertility has been built up by past applications of phosphatic fertilizers. The results would seem to indicate that at the lower pH values practically all the available P_2O_5 is derived from iron compounds, but it seems probable that at the higher pH values it is derived from both calcium and iron compounds.

Improvement of phosphate status.—In view of the foregoing, it seems

not unlikely that the ideal way to improve the phosphate status of a highly leached acid soil would be to apply liming materials in order to raise the pH value, together with regular dressings of phosphatic fertilizers. To raise the general level of a field would necessitate large quantities of both lime and phosphates, and consequently the cost per unit area would be high and probably prohibitive. Another possibility remains, which may be practicable on a large scale, viz. to create high fertility in spots, so that the cane plant may obtain the phosphate necessary for its growth from a relatively small proportion of the soil. Thus lime may be applied in the holes before planting, and fairly large amounts of phosphatic fertilizer in the holes at planting time. In ratoon crops similar spots of high phosphate fertility may be made by applying the fertilizer in a small furrow around the stool, or in holes made by crow-bars. In this way, during a complete rotation, many localized patches of high fertility may be created, as phosphoric acid in the soil possesses practically no power of movement. In the following rotation, the same method may be used, patches of high fertility being created in an area untouched in the previous rotation. The best form of phosphoric acid to be applied may vary with soil conditions. In strongly acid soils, an insoluble form like phosphatic guano is probably best, as the soil acids will tend to make it available fairly quickly, but for soils which are nearly neutral or only slightly acid, soluble phosphates may give better results.

Field experiments are being carried out to test the above suggestions relating to methods of application and the best form of phosphate to use.

Availability of added phosphate.—Fixation of added phosphate in a form which is only available with difficulty may be regarded as a source of temporary loss, since the crop is only able to utilize a small proportion of it, but in time it becomes of value, for this same property enables a high phosphate fertility to be created for the future with no danger of loss. The fixation tests of Demolon and Barbier [2] show that in lateritic soils highly deficient in readily available phosphoric acid, the power of fixation is undoubtedly greater than in those which are not so deficient. In other words, as the level of phosphate fertility is raised, the proportion of added phosphoric acid that remains available for plant-growth becomes greater, so that finally the quantity to be applied annually may be considerably reduced, without in any way reducing the quantity available for plant-growth. Yet in all the normal cultivated soils the power of fixation is high; and even where the fixation was least, it amounted to over 85 per cent. of that added. A very great difference is seen in the case of a grey soil from the Vallée des Prêtres, in which the power of fixation is much lower than in any of the lateritic soils, in that only about one-third of the added phosphate is fixed [4]. Consequently a higher proportion of the added phosphate is available for the plant-growth, and, moreover, its mobility in these soils will be greater.

It would appear that the soil phosphorus problem in Mauritius is very similar to that in Hawaii, judging from a description given by Heck [6]. His description of the various soil types seems to apply fairly well to some mentioned in this paper. Although the soils in Table 1 are classified according to their degree of laterization and maturity, previous work has

shown that all the highly laterized soils have low pH values, except where liming has been regularly practised. Again, the pH values of the red and of the dark-brown soils approach neutrality, and the soils of an intermediate degree of laterization have also intermediate pH values. The grey soils generally are nearly neutral, or even slightly alkaline. Consequently this table, as well as Table 3, might also be considered as an approximate indication of the effect of soil acidity on the availability of soil phosphorus, particularly in the first four soil types, in which the soils are products of lateritic alteration.

Although different experimental methods have been employed, the results are similar, in that the lateritic soils possess a high fixation power, and that when the soil is acid the phosphorus tends to be associated with the sesquioxides in the soil, whereas in a nearly neutral soil calcium phosphates may be an important source. Heck also states that the low-fixing soils are usually dark and often contain lime. These points have already been mentioned with respect to the grey soils of the dry regions of this Island that are covered with a savannah vegetation. Consequently it may well be that Hawaiian experience with phosphatic fertilizers may be an extremely valuable guide with respect to future policy in Mauritius.

The raising of the level of phosphate fertility, which may be done with little loss on account of the high-fixation properties of Mauritius soils, may be regarded as the basis of a sound fertilizer policy. To carry out such a programme entails a belief in a definite residual effect from previous phosphate applications, but it must be pointed out that the residual effect from one single application is likely to be so small, because of fixation, as to be almost negligible; on the other hand, the cumulative effect of several such applications may be of a high order of significance.

Summary

All types of Mauritius soils, with the exception of the grey soils, are liable to suffer from lack of available phosphoric acid, but in general the deficiency is more acute in the highly laterized acid soils. Recognition of soil type is insufficient to indicate whether phosphatic fertilizers are necessary, so that each block of land must be considered individually.

In general, the results of determinations of available phosphoric oxide by Dyer's method and by Truog's method agree fairly well, the biggest difference occurring in the highly laterized, immature soils, which are rich in organic matter. This difference may be due to the organic-phosphorus content of such soils, which is extracted by 1 per cent. citric acid and not by 0·002N sulphuric acid.

The highly laterized acid soils do not appear to contain any appreciable amount of calcium phosphate, the main supply being associated with the sesquioxides. In the more nearly neutral soils, however, there is evidence that basic iron phosphate supplies a certain amount of available phosphoric oxide, and at the same time it seems probable that there is also a certain amount of calcium phosphate. All these lateritic soils possess a high fixation power when judged by the test of Demolon and Barbier.

The grey soils of the dry districts, which cannot be considered as lateritic soils, have totally different properties from the above, and their power of retention is low.

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THE COMBATING OF ANIMAL DISEASES AND THE IMPROVEMENT OF STOCK IN EMPIRE COUNTRIES

Pt. I. THE COMBATING OF ANIMAL DISEASES

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Introduction

It will be realized that the scope of this article is so wide that it will not be possible fully to discuss the type of work which is being carried out in all parts. The subject can only be treated on general lines. Furthermore, the history of the cattle industry in our dominions has already been told in such detail that no attempt has been made to deal with it.

Before discussing the problems which must be confronted, it is necessary briefly to consider the position which cattle have held, and, to a considerable extent, still hold, in parts of the Empire. In Africa, for example, they have always occupied a very important place in the general life of the African. They have always had, and still have, much more than an economic value. They have a high sentimental value and determine, to no little extent, the owners' standing in the social sphere and in the tribal influence. It must be granted that a change is becoming obvious in some parts, but it will be many years before the old prejudices give way to the changes of progress. Number is still the principal factor: the importance of quality has not been realized. Even if the animals are of the most indifferent type, a large herd denotes an important owner. Accompanying this outlook is an ingrained prejudice against interference with practices which are deeply rooted in the history of the peoples. A further difficulty arises in that, although his cattle are a source of such pride to the African, he is an exceptionally bad stockmaster. The care of the herds is left to the boys of the village. Animals are penned during the night in kraals of very limited size. They are rarely changed, nor is the dung removed: and during the rainy season they become quagmires in which the animals stand belly-deep in mud. Their release in the mornings depends largely upon the temperature at which the boys will leave their blankets and huts. The choice of grazing-grounds is settled by custom or by the presence of shady trees under which the herds can rest during the heat of the day. Young calves are penned during almost the whole of their early life, without covering against sun or storm, and only allowed access to their mothers for limited periods, morning and evening. Consequently, they soon realize that they must obtain maximum sustenance in a minimum period, so that digestive and other troubles follow. This mixture of pride in his stock, and apparent indifference to their welfare, is one of the most surprising and difficult traits of the African cattle-owner.

In some of our more eastern colonies, cattle, and the domestic buffalo (which must be considered as part of the cattle industry), are still treated with indifference or neglect, but they occupy a dual position in the life of the indigenous community. Not only are they a source of food supplies

and used as draught animals for all purposes, but they are a part of religious observances and ceremonies. The problems of disease-control and improvement of quality are thus rendered extremely difficult. Any interference, even when undertaken with the highest motives, with practices rooted in mysticism, becomes fraught with grave danger. In some of our colonies the smaller stock are of little potential value, in others they are of greater importance than cattle. The improvement of sheep to a standard necessary to compete in the world's markets, either as mutton or wool, will have to be a gradual process. With goats, however, the position is somewhat different. The value of their pelts, even as the animals are to-day, has been recognized, and control of skin diseases, with advice on the treatment of skins for the market, is being actively carried on with most encouraging financial results. The pig still occupies a low place in the estimate of owners in those parts where he is found, and often lives in a semi-wild and insanitary manner.

Although the essentials of disease-suppression and stock-improvement are applicable under all conditions, the manner in which they can be carried out differs according to the state of the inhabitants, the accessibility of herds, the presence or absence of local demand, and so on. The problem is not limited to the stock of the indigenous owner. The presence of progressive Europeans has a distinct and highly important bearing upon it. The emigration of Europeans to our colonies has extended in some cases over a very considerable period: in others, the occupation of land not reserved for the local inhabitants has but recently begun. Indeed, there are still large tracts awaiting settlement. The first immigration has usually been associated with intentions other than agricultural. Excluding missionary endeavour, which will be referred to later, and military operations, the trader has usually been the first on the scene and has, in the course of time, been responsible for a limited and localized demand for agricultural produce. This demand, increasing according to settlement, has been met, or partly met, in an extremely haphazard manner, no attempt having been made to arrange for continuous supplies or adequate amounts. Only when demands have become large and insistent, has any attempt at organization been made, and, in those colonies where the natives are backward this has almost always been controlled by immigrants. The demands have, of course, differed in their nature in varying colonies and have even changed, as time went on, in the same territory. The necessities of life still remain the problem in some parts, working animals for draught and cultivation in others. In some colonies, where the outlook was considered to be purely agricultural, incredibly rapid industrialization, due to mining and similar ventures, has resulted in demands quite beyond local resources. In these the problem has been further complicated by the demand, during the development stage, for labour at wages which have tempted both Europeans and local inhabitants from their ordinary pursuits. Thus, when real endeavour was essential, many of those who should have taken part in agricultural advancement have been otherwise engaged. The stimulus for progress is demand. In many of our colonies this demand, other than the limited local one, is entirely absent: even if it should

suddenly develop, as in the case quoted above, the condition of the animal industry usually precludes the benefits being reaped. The fruition of disease-control and stock-improvement can only come after many years of strenuous and continuous effort. Both entail the expenditure of public funds, and, in most colonies, only the most limited amounts can be spared. Naturally, claims upon such funds as are available are made in respect of all manner of work, and that which appears to benefit the community in the shortest time must always receive favourable consideration. Apart from the Dominions and Southern Rhodesia, there is no part of the Empire from which there is an export of stock or produce (with the exception of hides and skins) which has any economical effect upon home or world markets. In few can it be said that the quality of the stock is such that the time can be accurately estimated when suitable animals, in large numbers and with continuity of export, will be able to compete with those already in possession of markets. The necessity, therefore, for pressing on with the work is, in some minds, entirely absent. Many will argue that it is foolish to commence, or continue, progressive effort. The only potential market, they say, is the home one and this is becoming increasingly embarrassed, day by day, from Empire sources and foreign competition. 'Why should public funds be expended on an objective which is of questionable potential value?' 'Let the European settlers improve their stock, at their own expense, if they desire to do so, but let us not raise up herds of improved stock for which a means of disposal cannot be found.' Such a view entirely loses sight of conditions that are dangerous to overlook.

Let us again take the colonies in Africa, including portions of the Union of South Africa, as an example. It will hardly be denied that the first step in cattle progress is the suppression of disease. That work has been carried on for some time with varying, but remarkable, success. Careful quarantines, controlled movements, preventive inoculation, and the like, have resulted in lowering the mortality to a very great extent. The consequence is that herds are increasing in numbers and will increase still more rapidly in the future. Greater numbers require bigger measures of protection. The greater the numbers of stock, the greater will be any calamity which may fall upon them. Can we go on endeavouring to protect from disease increasing herds quickly approaching the stage, in some parts, where the available grazing will be totally inadequate? Can we view with equanimity a not far distant future when the calls upon the pastures will involve the destruction of herbage, and erosion, an urgent problem to-day, will turn vast tracts of land into waterless wastes? Lowered vitality of stock will create conditions under which no protective measures will suppress disease, and one of the major scourges will sweep across the continent. We have commenced the work and we cannot stand still and mark time, nor can we adopt a retrograde policy. Disaster awaits either. It has been shown that stock play an important part in an African's outlook. The political effect of a disaster, and the subsequent unrest, need not be described. Incidentally, the European settlers will share in the tragedy and the efforts of years of strenuous work be lost. It may be said that such conditions apply only to Africa. To some extent that is so, but protection against disease is

having its inevitable effect in all places where the cattle population is sufficiently large to necessitate the maintenance of veterinary staffs. Disease-suppression without improvement in quality, stamina, or other conditions can scarcely be justified. Indeed, it will entail true progress in whatever manner demand dictates, if slaughter of unwanted animals is to be avoided, for a dual policy of protection and waste is absurd. Even in colonies where, as yet, the value of cattle depends upon their use as working animals, a policy of *laissez faire* cannot be contemplated, as, in the course of time, this method of carrying out work must give way to mechanical devices and stock become of value in other directions.

No apology is made for including in this article a somewhat lengthy introduction, as, otherwise, all the problems which confront those engaged in improving the stock industry would not be realized; they are of such vital importance, and the indifference to them in some quarters, even official, so lamentable, that they cannot too often be reiterated. The necessity for progress, and for the right men to guide it, must continually be stressed. Too much time has already been lost.

Combating Disease

The suppression of disease must, as has already been pointed out, be one of the first steps in the progress of the cattle industry. Its necessity need not be argued, but it has a secondary effect in that it is one of the speediest ways of obtaining the confidence of owners, no matter in what sphere of life they may be. To preserve property, now and in the future, must inevitably evoke gratitude, and inculcate a desire for further combination of effort which will be of the utmost advantage. The average European settler, and others of enlightened standing, understand the nature of the work and usually co-operate. Even in these cases, the effect of well-executed precautionary measures, irksome though they may be, must always tend to better understanding and ensure fuller liaison. With less intelligent owners, it is, of course, often quite impossible to discuss the nature of the measures which it is intended to carry out. By some means or other (any question of force being ruled out unless the circumstances are most exceptional) the owner must be won over to co-operation on a small scale. The results of the first efforts largely decide the future attitude of the owner and his neighbours. The beginning should be made, where possible, with some influential member of the community, so that the object-lesson may be emphasized. Needless to say, whatever the work undertaken, it should be organized, and carried out, with the strictest regard to reducing accidents and bad results to a minimum. Examples in all parts could be cited to show the effect of measures hastily conceived and indifferently executed. Large-scale operations, with insufficient staff or equipment, should never be attempted, unless the cause against which the precautionary measures are taken is such that the consequences of total inaction may be disastrous. Circumstances may arise when even inadequate measures may obtain some success and relieve what might otherwise be an intolerable situation. In all other cases restricted action, even if quite serious losses obtain elsewhere, is the only policy which will be followed by success among

untutored people. The object-lesson is of such importance that what may appear to be a callous policy is justified.

Disease is divided, in the mind of the administrative veterinarian, into two classes: that which exists within his territory and that which may be introduced from without. His mind naturally first turns to the latter. He may be faced with many diseases in his territory but there are usually still others which may gain entrance. Some of the precautionary measures which are taken to prevent the importation of disease have been severely criticized, particularly that of total prohibition of the import of animals. At the present time New Zealand prohibits the importation of cattle from the United Kingdom owing to the presence of Foot and Mouth disease in the latter. It is not intended to discuss whether this action is, or is not, justified. It is quoted to demonstrate to what extent some countries are prepared to go to limit some of their problems to those which already exist. To the man who is sufficiently fortunate to find himself in an island territory, this first portion of his task is comparatively easy, but even he is often faced with difficulties which completely baffle him. Disease appears in spite of his efforts. The history of Foot and Mouth disease in England demonstrates the difficulties which have to be faced. Further, it is sometimes possible definitely to ascertain the means by which infection is introduced, only to find that the necessary measures cannot be carried out. Not infrequently, insufficient financial means, with its sequel, depleted staffs, are available; quite often, the economic consequences would render their imposition quite impossible. It is of little use to suggest the prohibition of an essential foodstuff, or of necessary merchandise which has to be imported in implicated, or suspected, packing. Theoretically correct, or even proved, precautions often have to yield to those which can economically be carried out. If the difficulties confronting such a one are many, how much more serious are they in a territory which forms part of a much wider area or even of a continent? Take the situation of Palestine, of India (or any locally governed portion thereof), or a colony in Africa. The borders are often a geographical line, not infrequently quite beyond, or only inadequately within, the control of the responsible government. The inhabitants of some adjoining countries recognize no boundary and move across it, with their herds, at will. Kenya and Tanganyika are typical in this respect. The boundary, a geographical line, cuts in two a great tribe. From time immemorial, portions of this tribe have used certain differing grazing-areas and watering-places as the seasons changed. To-day, certain Kenya natives cross to Tanganyika to graze or water their stock, and vice versa. Yet these two territories are under different Governments, each with separate control regulations. They are not even under an agreed policy as regards some of their diseases. Take the case of Palestine, having across its borders a somewhat lawless people amongst whom veterinary control measures are unknown. In all parts of Africa a wedding usually entails the passing of stock as part of a bridal dowry, and the utmost ingenuity will be used to ensure delivery in spite of prohibition of movement or other regulations. And there is always the problem, common to so many of the less advanced colonies, of game movement.

It is axiomatic that precautionary measures against importing disease should begin at the borders. Now in the majority of colonies the more controlled areas are those which have first been settled for administrative, or other, purposes. The places for the former have often been selected for ease of communication, and the latter have resulted from missionary effort or industrial activity. Areas remote from these are usually difficult of access or only partially under control. Consequently, precautionary measures are often quite impracticable where they should first be started, i.e. at the borders. Operations have, at first, usually to be limited to the areas of greatest influence and control, and gradually extended. Thus, measures designed to exclude disease are often those for the suppression or prevention of existing ones. The more settled areas naturally have in them the greater number of European or immigrant stock-owners, and this has led to a charge being made, by some critics, that public funds are the more readily spent upon those who can the more easily press their requirements or complaints. Unprejudiced study would dispel such a charge, as it is surely logical that the herds of all owners are safer if surrounded by a buffer area of stock amongst which action for the control of disease had been taken.

Of what do the precautionary measures consist? They may be divided into four groups:

I. Quarantine at ports of entry, where it is possible.
II. Measures designed to check the carrying of the causal agent.
III. Measures designed to confer an immunity upon the animals themselves.
IV. Measures designed to prevent that debility which renders an animal more prone to attack.

I. In the more settled, and island, colonies, this group is important. If animals, or other carriers of disease, can only gain access at specified points, then the work of prevention is simplified to inspection, treatment, or quarantine for such periods as is considered necessary in the light of the available information regarding their source, the route, the length of time in transit, and other relevant matters. Advantage is often taken of the quarantine period to render the animals immune to certain local diseases by the inoculation of sera or vaccines. It has been pointed out that circumstances sometimes render adequate precautions at these ports quite impossible. It is usual, however, to continue those which are practicable, on the principle that at least some of the danger is eliminated.

II. Many of the major animal diseases are caused by organisms or viruses which have a separate existence outside the animal itself, or are derivatives of organisms which are introduced to the animal. Although not entirely correct, that statement is sufficiently so for practical purposes. Some of the causal agents are easily recognizable microscopically, some are ultra-visible. The manner in which some can be transferred from animal to animal is known and can definitely be guarded against. In some cases the means of transmission are very numerous: in a few information regarding transference is yet to be obtained. In many colonies one of the methods adopted to prevent spread is one which is impracticable in more civilized colonies. It consists in establishing a

cattle-free belt by moving all the animals in an area to a distance which is governed by the nature of the disease and the presence of suitable grazing and watering facilities. These belts may remain free from stock for a limited time only, but in some cases they have been maintained for so long that the owners of the stock have settled in the new areas. Occasionally, such belts are created as a permanent safeguard against disease from an adjoining territory. Fortunate indeed is a country which can maintain a permanent stock-free belt along a threatened border. Certain of these are in existence to-day. It will be realized, however, that it is by no means easy to bring about the evacuation.

The quarantining of districts, areas, or even herds, is a less difficult matter, but the relative smallness of the area often increases the difficulties of maintaining the isolation. Owners usually establish only grazing posts in the areas to which the stock have been moved, and proximity increases the tendency for the supervisors to leave their charges for a while in order to visit their homes. The animals themselves strenuously endeavour to return, and constant vigilance is necessary to prevent them. Nevertheless, this isolation is of enormous value in suppressing more localized outbreaks. Of the greatest importance in this group is the practice of dipping. The diseases caused by tick-borne organisms are of considerable economic importance in the majority of our colonies, and particularly those in tropical, or semi-tropical, zones. Indeed, where imported or highly graded stock is kept, it may almost be said that where there is no dipping, there will be no stock. Dipping is proving one of the greatest factors in live-stock improvement in many parts of the Empire. It has an advantage other than that of disease-prevention. When dealing with the less intelligent people, the weekly, or fortnightly, meeting at the tank provides an opportunity for inspection and educational work which is of great value. This aspect will be enlarged upon later. Nevertheless, dipping is not an unmixed blessing, and is accompanied by a grave danger. Indigenous animals of an undipped territory possess a very high natural immunity to the local strains of organisms carried by ticks. This immunity is a great asset and every effort must be made to maintain it, in as high a degree as possible, until such time, in the far distant future, when the ticks themselves have been eliminated. It should be the practice, therefore, to leave undipped all unweaned calves and to interrupt the continuity of dipping amongst the older animals at the period of lowest tick-activity. In many colonies this period is associated with the colder weather or the seasons of limited, or no, rainfall. Indeed, circumstances often render dipping either impossible, or inadvisable, at portions of the year. One thing must always be borne in mind. The season during which constant and careful dipping should always be enforced is that immediately preceding the obvious tick-activity. At this time the larvae are often feeding upon the animals and their destruction reduces the potential tick population to a very considerable extent. It is essential, however, that the greatest care be taken when the practice is first begun and an antidote to arsenical poisoning be made available. Any untoward incident may result in a severe set-back. Cattle should never be dipped when they are hot from a journey, and should always be

given an opportunity to drink immediately prior to immersion. One other precaution: the danger of spreading other diseases, when cattle come from all parts of an area surrounding the tank, must be guarded against.

Whenever cattle have been conveyed by rail from one district to another, the trucks should be disinfected. This is imperative when transmissable disease exists *en route*. All manner of reagents are used for this purpose, but the most efficaceous and safest method is to use live steam. Depots for this work have been established in some colonies. The boiler from an old locomotive is used. Litter is removed from the trucks and destroyed by fire, and the inside is cleansed by a stream of live steam, under high pressure, directed upon it through an armoured hose pipe. If the work is carried out in a careful and methodical manner, every crack and crevice can be efficiently treated, and the whole rendered sweet and clean. All fear of poisoning future occupants is avoided, and the work can be carried out with dispatch.

When dealing with a disease such as Foot and Mouth, the virus of which can be carried by so many agencies, the most elaborate precautions have to be taken. The actual mortality from this disease is seldom important; the losses being either from, or the result of, a consequential debility. The recent action taken by New Zealand has been referred to. One other example may be cited. When Foot and Mouth disease broke out in Southern Rhodesia some four or five years ago, and, subsequently, in the Union of South Africa, not only was a complete embargo upon all animals from these territories imposed by Northern Rhodesia, but the importation, or in-transit, of all vegetable or animal produce, all articles derived from vegetable or animal sources, and all merchandise packed in material derived from the sources indicated, were prohibited. Wagons and motor-cars were compelled to pass through disinfecting baths, and passengers' luggage was examined and suspected articles removed. The resulting dislocation of trade was acute in both Northern Rhodesia and the Belgian Congo, a portion of which was quite cut off from the source of much of its supplies. The case is cited to show how complete must be the control, and to what extent dislocation of trade can be affected, when a country is threatened by one of the major diseases.

Adequate control of a disease such as rabies, where the reservoir of infection is in wild carnivora, is often impossible. Palliative endeavour is limited to the registration of dogs and the destruction of those not claimed, and similar measures for lessening the possibilities of transferring the infection to man.

III. Without any doubt the immunizing of animals against disease is now one of the principal factors in the prevention and suppression of disease. Problems which presented grave worries some years ago are now faced with some confidence, if finance, organization, and staff are assured. The list of diseases which can be controlled by inoculation is steadily growing and includes anthrax, 'quarter evil', rinderpest, contagious bovine pleuropneumonia, bovine contagious abortion, anoplasmosis, and piroplasmosis. The first two were important formerly and even to-day they cause grave loss where action cannot be taken. It is the practice for the more backward peoples to eat the meat of such animals

as die. In many cases carcasses are cut up and transported to various villages. Thus, spores of the organisms from the blood are scattered over wide areas, with subsequent outbreaks of considerable mortality. Safe and effective vaccination is now available. Reference has been made to the natural immunity of indigenous stock to the local strains of tick-borne, causal organisms of certain diseases, particularly redwater and gallsickness. Imported stock may have a lower immunity, or none at all, according to conditions in the country of origin. It is now possible to confer an immunity upon imported stock. The process, however, is of some duration and not unattended by risks. Thus, it is usually confined to pedigree animals imported for improving the herds of a progressive farmer or rancher. Some years ago the benefits of conferring immunity, even though it was not complete against all strains, before such cattle as are exported from England were shipped, was recognized. To-day, a station exists at London docks where animals are treated under conditions which are extremely favourable. The virus is supplied by the laboratory of the Ministry of Agriculture at Weybridge, and is composed of strains received from as many sources as possible.

A suitable vaccine for controlling contagious bovine abortion is still being sought. A 'live' vaccine is available, but it is only used in exceptional circumstances and should not be introduced to clean herds. It may be used where conditions make it advisable to endeavour to control the disease in the shortest possible time. The result is often the loss of a year's calf-crop (though there have been exceptions), but this is previously taken into consideration. Immunity having been established in the breeding-herds, there remains only the treatment of all heifers prior to the time when they will be ready to receive service. The less drastic manner of dealing with the disease is by diagnosing infected animals by means of the agglutination test, and placing them in complete isolation from all others. They are disposed of as circumstances permit. The policy is, of course, continuous. It is usually adopted only in the herds kept solely for dairying purposes.

Although a means of immunizing cattle against pleuropneumonia has been known for many years, only fairly recently has it been carried out in an adequate technical manner. In the Union of South Africa, where the disease existed for so many years, a 'salted' (recovered or immunized) animal was of the greatest value in that, although it might break down, it enabled necessary work to go on. Farmers used to dip small pieces of wool into the exudate from the pleural cavity of an animal dead from the disease, and insert this into an incision in the tail of a clean beast. The virus was thus introduced into the bloodstream, but the operation was often carried out under conditions which resulted in septic sequelae, and swellings and sloughings of the tail and portions of the quarters were common. The swellings were countered by amputation of the tail or the actual cautery was applied to the quarters in the form of a ring. It was no uncommon thing to see spans of oxen, in many districts of South Africa, with only stumps of tails and with burned circles around the quarters. The method was crude, but it had advantages under the then existing conditions. The treated animals, however, were quite

frequently infective, or potentially infective, reservoirs and capable of spreading the disease amongst clean stock. Although the pleural exudate of diseased cattle is still the essential factor in immunization against pleuropneumonia, it is now treated in an adjacent, or field, laboratory in such a way that a more controllable reaction results upon its injection, and one which does not result in creating future reservoirs. The disease has quite recently been eliminated from Bechuanaland by a combination of immunization and segregation of infected animals, which has proved the efficacy of the method upon a very large scale.

One of the diseases most dreaded by veterinarians is rinderpest. This may either appear as a scourge which sweeps through a territory with a truly devastating mortality, or it may settle down amongst stock which has become partially tolerant, and, as a result, presents a problem the solution of which is quite beyond the present practical and financial resources of the territory to solve. In those places where the disease does not exist it is possible that both these forms would follow the introduction of infection, the one following the other. Immunity from the disease can be produced, but the practice is not usually adopted in places other than those immediately menaced. The immunity is of two kinds—active and passive—varying according as antiserum is introduced with the virus or at a later date, and with the amount administered. Steps to induce active immunity are never taken except in districts where the disease actually occurs, as there is always the danger of setting up an infection which may result in an uncontrollable outbreak. Passive immunity is, as the name indicates, of limited duration and adopted amongst clean cattle menaced by an approaching, or existing, infection.

Work is steadily being carried on which has as its objective the conferring of immunity against other diseases. Particularly in connexion with 'virus' disease is an effort being made, and successful reagents are available against horse-sickness and 'louping ill' of sheep. Next to complete elimination of disease, or its causal agent, immunization forms the most satisfactory, as well as the most spectacular work of the veterinarian in the Empire.

IV. So many of our colonies are situated within zones in which periods of drought or insufficient rainfall are a normal or frequent feature, that the maintenance of stock in health becomes a serious problem. Pastures not only provide the principal diet: in many cases they are the only source of foodstuffs. In parts of the year, therefore, many herds have to face conditions varying from insufficient nutrition to maintain complete health down to an almost complete absence of grazing. Their own state varies from poor to emaciation. Indeed, in some years it is almost miraculous how some of the animals exist at all on the available nourishment, and one wonders why the resultant mortality is not a total one instead of being merely heavy. Lowered vitality is a great factor in the susceptibility to, and spread of, disease, and the means for preventing it are amongst the most important with which a veterinarian is called upon to deal. As, however, he is by no means the only one concerned, and as they are most closely allied to the problem of stock improvement, they will be discussed under that head.

(*Received August 12, 1936*)

SCIENTIFIC PROBLEMS OF THE POULTRY INDUSTRY[1]

I. INTRODUCTORY

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(*Blackpool*)

THE poultry industry of Great Britain and, I believe, of all the world is what we might term 'self-made': it has been built up by poultry-breeders themselves upon experience gained by much hard work, many disappointments, and some minor disasters that have brought financial ruin to those upon whom they fell. In the process of 'building up' we in Britain have had little help from the State, and what help we have had has come after long and arduous fights with those who seem to regard the poultry industry as the Cinderella of agriculture, and hardly worthy of mention except for the period 1914–18 when this country was hard put to it to feed itself, and especially to provide foods that would win back to health and strength the thousands of men occupying our hospitals and convalescent camps during those awful years. Then the importance of the new-laid egg was acknowledged, as also was the value of the succulent and strength-giving chicken; the industry was pressed to increase its output; and promises were made to it that have never been fulfilled. Once again we find it being used to barter with in trade pacts and trade agreements with almost every country in the world, and, I submit, the poultry industry is being sacrificed to the disadvantage of the country generally.

This preamble may seem unnecessary, but I wish to place before you a few facts to bring out the importance of the poultry industry to these Islands. Foremost is the provision of home-food supplies of the highest possible value in health and in sickness, in peace and in war. The total value of eggs and poultry produced in the United Kingdom has, from about 1927 until recently, exceeded in total cash value that of wheat, oats, and barley combined, also that of the whole vegetable crop, and that of the potato crop, and is exceeded only by milk and beef, the total value being about £21,000,000. You will, I hope, agree with me that those who are working on the problems of this industry are doing really good service for our country, and for hundreds of thousands of people engaged in the industry (recently estimated by the Reorganization Commission for Eggs and Poultry as over 500,000 in England and Wales alone), behind whom must be at least an equal number engaged in growing, milling, and mixing foodstuffs, railway and haulage workers, appliance manufacturers, makers of wire-netting, boxes for eggs and chicks, and the thousand and one items purchased and used by poultry farmers generally. I also wish to tell those gentlemen who are to reply to me, and all others who are engaged on problems with which the poultry industry is troubled, that their splendid efforts are very much

[1] The four papers under this head were read to Sections D and M (Zoology and Agriculture) of the British Association for the Advancement of Science, Blackpool, September 14, 1936.

appreciated by those of us who for lack of a better term may be called the more enlightened or more open-minded breeders, who number at least 99 per cent. of those engaged in the industry.

The three main problems affecting the poultry industry are concerned with: (1) breeding, (2) nutrition, and (3) disease; and I put them in this order, for whilst it is not for me to suggest how to overcome these troubles, I do submit that the first essential is soundness of constitution in our breeding stock, without which we cannot hope to make progress, no matter how we balance our feeding in accordance with the results of scientific research or of experience gained under field conditions. Nor could we expect to combat such disease troubles as may fall to our lot, if we had stock weak in constitution and of low resisting powers; therefore I wish those who are to follow me to appreciate that it is understood they are not expected to work miracles on birds that have been bred without regard to constitutional vigour.

Breeding problems I place in the order: (*a*) fertility, (*b*) fecundity, (*c*) hatchability, and (*d*) stamina or 'liveability'; and so I will deal with them.

Fertility has for some years been a matter of concern to the industry, especially in relation to some of our heavy breeds, both the laying or utility type being affected. Fertility among such fancy breeds as Indian Game, Orpington, Brahma, Cochin, and Wyandotte has been at a very low level, and among the Wyandottes the White seems to be more prone to low fertility than do the other colours. On this point breeders would appreciate enlightenment and help. Low fertility is also the cause of much loss among breeders of utility White Wyandottes, and it is often stated to average as low as 50 per cent. over the hatching period, whilst other breeds, kept under identical conditions, give from 85 to over 90 per cent. average fertility. This is plainly a matter of vital importance, as also is that of hatchability, which seems to be fairly closely allied with the percentage of fertile eggs in a setting. What the industry would like to know is whether high or low fertility and hatchability are inherited; and if so, how can a line or strain of highly fertile birds be developed without detriment to other vital factors, such as egg-size or body-size?

Fecundity is a problem about which much has been written, but the concern of breeders is how to find out whether a bird bred from a highly fecund dam and sired by a son of a highly fecund dam has inherited a high fecund factor, and whether such a bird will pass the character to its offspring (without, of course, having to resort to progeny testing). Some years ago certain writers suggested that measurement of the skull of a bird was a reliable guide to fecundity and prepotency. To be candid, I never understood their reasoning, and this no doubt applied to most of the poultry-keepers who read the articles, and to many who tried to put their findings into practice. Is there any fairly reliable guide to the selection of highly fecund and prepotent birds?

Hatchability seems to be closely connected with fertility, though breeders do on occasion find with hens that are highly fertile, but poor breeders, a fairly large percentage of the chicks dying in the shell. Is there any advice that can be given on this matter? When one finds a hatch well up to the average, except for one or two females, the layman

has difficulty in deciding the cause, and wonders whether any of the progeny from these birds are likely to behave similarly when they in turn are bred from.

Stamina or 'liveability'. Can our scientists tell breeders the reason why apparently healthy, vigorous birds of two or more years old, which have lived under ideal free-range conditions, produce progeny that are lacking in stamina or vitality? Or if they cannot, can they tell us how to select birds which will produce strong healthy progeny that can live three years at least, and be profitable, and in turn produce progeny as strong and robust as themselves? Replacement of stock on both pedigree and commercial farms is a big item annually, and if it were possible so to breed that replacements could be reduced from the present annual figure of 60 per cent. or more on commercial farms to even 40 per cent., much good would result, and balance-sheets would become more healthy.

Nutrition. During the past few years the poultry industry has been under the effects of general trade depression, with consequent low prices for eggs and poultry. This has had a serious and, I fear, a very damaging effect upon every branch of agriculture, so much so that, had it not been for the low prices of feeding-stuffs ruling throughout this period, there would not have been any possibility of carrying on commercially. World prices for grains and feeding-stuffs usually fed to poultry already show signs of increasing to a level such as is required for the well-being of the grower, so that unless eggs and poultry produce rise alongside, which hardly seems likely, the poultry industry must find less costly but equally satisfactory foods. Further, it is essential that, when such feeding-stuffs as wheat offals rise in price, as has happened recently, due largely to a push by the trade through advertising, we poultry farmers should be able to take the alternative, lower in price and at least equal in food value, and at the same time produce as many eggs or as much flesh. It is not on analyses alone that food-values must be determined, and if our nutrition experts can be of real help in this matter we shall be thankful, for feeding-stuffs are responsible for about 60 per cent. of the costs of production. Amongst grains we usually feed maize, wheat, and oats, and to a much smaller extent barley and dari, and what is required is information as to which of the lesser used grains can be used to replace any of the former three, when any of these become prohibitive in price, remembering all the time that we must maintain health and egg-output or flesh-production, whichever is concerned. Cheap food is dear food when results are poor. Further, we should like to have guidance as to the relative value of dry and wet mash from a digestive point of view, and if wet mash is best, is the mere adding of water—hot or cold—the reason for improvement? Also we would welcome information on the relative value of animal and vegetable protein, both for young chicks and layers.

Disease in poultry has been given prominence during the past five years or so, and whilst much has been done during that time by both veterinary workers and breeders, much still remains to be done before we are back once more at the 4 to 5 per cent. death-rate during the first year's lay, which we 'enjoyed' until about 1930. Since then we have

suffered increasing mortality, especially during the first 12 to 15 months of the bird's life, not only in females but equally in males. Though deaths during the first 10–12 weeks have been considerably reduced (and would be very much more if we could be rid of coccidia), the percentage of birds lost between one day and 15 months has considerably increased; but there are signs that we have turned the corner. I suggest, however, that this improvement is due more to the adoption of saner methods by breeders than to the research worker, by which I mean that the commercial egg-farmer is not now breeding from forced-to-lay stock, or rearing in such large numbers as he did in the recent past, and that to bring back the death-rate to normal once again we need cures for coccidiosis, worm-infestation generally, for paralysis in its various forms, and preventives for cholera, fowl plague, and laryngotracheitis. I do not think we need trouble ourselves much about diseases like bacillary white diarrhoea or avian pox, because means of detecting carriers of the former disease and vaccination against the latter are fully effective and have been of considerable cash value to the industry, though I am sorry to say there are still those who decry them. The primary troubles of the present day are coccidiosis and parasitic infestation generally, such as tapeworm and caecum worm. These are causing heavy losses and a cure or an easy and cheap means of eradication from the fowl, also a cheap but effective treatment of infected land, would be a real boon to the industry. Fowl paralysis is the breeder's nightmare and must be eliminated or controlled in some way if the industry is to progress or even maintain itself, and whilst up to now my farm has kept clear of such trouble, I do fear for the future. When such eminent men as Major Dalling and many other research workers tell us that they do not think there is a farm clear of this trouble the world over, and if apparently clear now, is not likely to remain so for ever, you will agree that the position is serious and warrants a united and very determined attack being made against it both by scientists and breeders. I do not exclude the latter, for in my opinion they can do a big share in the control of fowl paralysis, as in the control of disease generally. I know little about fowl cholera, fowl plague, and laryngotracheitis, and can only ask that no effort be spared by the Government, the scientist, and the breeder to eliminate them, or at least to reduce their incidence. Only by the very closest co-operation between all concerned can progress be achieved.

II. CONSTITUTIONAL VIGOUR IN POULTRY

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When referring to the present state of our poultry stock, constant use is made of the terms 'stamina', 'constitutional vigour', and 'liveability', but so far as one is aware, attempts are rarely, if ever, made to define exactly what is meant by these words, and in the minds of many they are synonymous. It will be necessary, therefore, at the outset to define the precise meaning it is proposed to attach to these terms in this discussion. This perhaps is best done by reference to the ideal after

which the breeder is striving: the production of birds which can live and function at an economic level over a number of years.

If we confine the use of the term 'liveability' to those birds which remain alive for a considerable number of years, it is found that such individuals do not necessarily conform to the breeder's ideal, since a great number of them will exhibit, comparatively early in life, ovarian functioning well below an economic level. Most birds fail to give a sufficient number of eggs after two years' reproductive functioning.

Stamina may be defined as the power of a bird to resist variations in the environmental conditions, whether of nutritional, pathological, physiological, or of climatic origin, so that relatively long life (or 'liveability') is attained. But this again need not necessarily be allied to economic production for an extended period in the life of the bird.

We are thus left with the question of constitutional vigour. Although some, no doubt, would hold that this term is synonymous with stamina, there appears to be considerable justification for endowing it with a wider significance and employing it, as it is proposed to do here, to denote the ability of the individual to maintain a certain level of bodily functioning for a period of time longer than that normally characteristic of the average hen.

There is little doubt that, with well-known exceptions, 'liveability' within the range required by the breeder may be taken as an inherent quality of all birds. It is known that the normal expectation of life may be seriously interfered with by the action of specific genetic factors, such as lethals and sub-lethals, which possibly are responsible for the extremely high embryonic mortality met with during incubation, particularly in certain breeds.

In the same way, it may be possible to attribute to the action of genetic factors certain constitutional break-downs in later life. The evidence gained from a study of fowl paralysis, for instance, has suggested that the operation of inherited tendencies may make a particular strain of birds susceptible to this condition, and the age at which it becomes evident may vary from a few weeks up to three years or more.

But if these individuals with undesirable genetic make-up are excluded, there still remains a large proportion of stock exhibiting what may be termed a lack of stamina, i.e. an inability to cope successfully with environmental variations. It is interesting, in the absence of any positive evidence, to speculate upon the causes of this lack of stamina in modern poultry stocks. It may be due to a loss of specific genetic qualities from flocks in general, which formerly enabled birds to adapt themselves fully to the environment in which they passed their lives. On the other hand, it may be that the environment has changed appreciably, so that the genetic constitution of a previous generation no longer suffices to ensure long life. The gross environmental changes that have come into play may involve nutrition, husbandry, or increased exposure to infection.

Without positive evidence as to the inheritance of stamina, the possibilities outlined suggest two fundamental practices of breeding: (1) either an attempt should be made to breed a race of birds which can resist

successfully all reasonable environmental changes, of whatever origin, or (2) the environment should be controlled, so that, except for accidental death, every bird should realize the normal expectation of life for the species.

The fact that birds differ widely in their ability to flourish in a given environment suggests the possibility of breeding stamina into a stock, but since health depends on so many different factors, no simple experiment to determine its mode of inheritance could be staged. Since stamina is to be shown by the ability of the bird to survive in the presence of adverse conditions, the method of husbandry adopted would necessarily be the extensive one, because extreme climatic changes may be a major factor in determining loss of the condition. If, however, control of environment is sought, then the most rigid intensive system would be employed in order to eliminate such variables in climatic conditions, exposure to infection, nutrition, and husbandry.

An approach to the latter set of conditions obtains in the flock of Brown Leghorns maintained at the Institute of Animal Genetics of the University of Edinburgh, where the fowls have been kept under a rigidly controlled intensive system since 1929. Importation of outside birds has been infrequent, and the greatest care has been taken to minimize the possibility of infection reaching the stock. The data in Table 1 show that under these conditions mortality figures have remained remarkably low in the first two years of life, and have risen but gradually to the fifth and sixth years, when a high death-rate is only to be expected.

Two explanations of this are possible: (1) that the environment in which the birds are kept is peculiarly adapted to them, or (2) that they possess natural stamina. The latter postulation could only be put to test by exposing groups of these birds to different conditions of husbandry, and, while attempts are being made to follow up the history of stock which has been dispatched to different parts of the country, the question must at present remain open.

If, however, insufficient evidence for a detailed discussion of stamina can be adduced from our records, it is still possible to examine the question of what has been defined as constitutional vigour.

Although a simple measure of productivity may be arbitrarily evolved with regard to this particular character—constitutional vigour—this measure can only be attained if the bird possesses at least a number of desirable qualities. If we suppose, for the present, that vigour is inherited, then it must be obvious that for a bird to express fully its inherent genetic constitution, it must possess the necessary structural characters, such as body-size and conformation. It must also be equipped with an efficient digestive system capable of economic utilization of food consumed, together with sound respiratory and reproductive organs. In fact, when vigour is analysed to this extent it is readily seen that we are concerned not with one quality only—productiveness—but with almost all the qualities and characters that go to make up the individual. A break-down in any one of the systems mentioned involves a loss, or at least a lack, of vigour, and to refer to constitution as a single

desirable quality, which may or may not be inherited, is a manifest absurdity.

The sound functioning of the organs of the body depends not only on their correct structure and form, based presumably on their individual genetic constitutions developed in a suitable environment, but also on the proper functioning of the glands of internal secretion. It is probable that where prolonged functioning is concerned, break-downs are more liable to occur in these glands than in the organ systems which respond to them. Glands like the pituitary, ovary, and thyroid are probably fundamental factors in constitutional vigour. If this is so, then we are not primarily concerned with the large number of factors responsible

TABLE 1. *Mortality in Female Stock, 1929–1935 inclusive*

	Number of birds	*Died*	*Percentage dead*
Pullet year . .	692	36	5·2
2nd year . .	253	8	3·1
3rd year . .	82	9	11·0
4th year . .	32	4	12·5
5th year . .	14	4	28·5
6th year . .	4	1	25·0
Totals . .	1,077	62	5·75

for every part and function of the individual when considering the question of vigour, but are probably only dealing with a few which can extend for a prolonged period the high state of vitality and productiveness characteristic of birds in the first two years of life.

It is now proposed to examine the problem with regard to our own stock of birds, and the first step is to devise a standard of vigour. To this end, it has been decided arbitrarily that any bird which lives for a minimum of three years, and produces not less than 140 eggs in her third year of production, shall be considered to possess this quality.

Before considering the possibility of vigour being transmitted from parent to offspring, it will be necessary first to determine its incidence in the general stock, and secondly, to examine the possibility that factors such as the age of the dam, have any effect on its appearance. Unless the influences of extraneous factors on the quality are first estimated, much of the value of any data obtained by experiment may be vitiated.

The data relevant to the incidence of constitutional vigour are given in Table 2. They are drawn from a population of birds that, for various reasons concerned with genetical experimentation, it was decided to keep for recording purposes until they died. They have not all been selected primarily for their qualities as possible breeders, either to maintain or increase the productivity of the stock. This group of birds was bred at the Institute during the years 1928-1932. As previously mentioned, they have been kept under the intensive system, and maintained under constant conditions of husbandry and nutrition. It is not suggested that from such a small number of individuals conclusions of far-reaching importance and application may be deduced, but at least they provide

some basis for discussion. As far as I am aware, the problem has not yet been investigated systematically.

TABLE 2. *Experimental Data relating to Constitutional Vigour*

Group	*Pullet production. Number of eggs*	*Number of birds*	*Alive at end of 3rd cycle*	*Number laying 140 eggs or more for 3 years*	*Percentage of live birds exhibiting vigour*
1	240–259	7	5	4	80
2	220–239	15	9	8	89
3	200–219	20	15	9	60
4	180–199	12	8	6	75
5	150–179	6	5	4	80
	Totals	60	42	31	74

The view has been frequently expressed that decline in vigour may be associated with the intensive selection of birds giving high egg-yield in their pullet-year. It is interesting to examine the data from this standpoint, since the birds included present a range of annual egg-yield as pullets from a low point of profitable economic production up to what may be considered as reaching the highest average figures for this breed. From Table 2 it will be noted that the ability to exhibit productivity over a number of years is not characteristically correlated with any particular range of pullet production.

With regard to the incidence of vigour, examination of the total figures shows that in this stock 74 per cent. of the birds at the end of the third cycle of egg-production possessed what we have defined as constitutional vigour.

TABLE 3. *Average Yearly Egg-production*

Group	*Number of birds*	*1st*	*2nd*	*3rd*	*4th*	*5th*	*Total eggs for 3 years*
1	4	249	172	140	159 (2)*	..	561
2	8	228	165	160	..	..	553
3	9	210	166	164	159 (4)	148 (1)	540
4	6	192	195	161	149 (2)	141 (1)	548
5	4	168	155	150	141 (1)	..	473
Average	31	211	171	157	155 (9)	145 (2)	539
Production expected		211	186	164	144	127	

* Number of individuals.

In Table 3 the average production figures for the birds included in Table 2 are given by years, and it will be seen that some of the birds have reached our standard of productivity in the fourth and even in the fifth year. The figures for expected production were derived from the findings of Brody, Henderson, and Kempster (1923), who showed that

on the average each year's egg-yield is 88 per cent. of the preceding year's production. Referring to their results, Jull[1] considers that since the decline in production was not nearly so great as that reported by many other workers, it may mean that their stock was genetically superior from the standpoint of maintaining egg-production at a high level from one year to another. An analysis of our records of birds exhibiting vigour shows a reasonably close approximation to the figures of Brody, Henderson, and Kempster, and it may be inferred therefore that there is a possibility that these birds are exhibiting a genetically superior constitution.

TABLE 4. *Number of Persistent Producers in relation to the Age of their Dams*

Age of dam	*Total number of birds*	*Persistent producers*	*Percentage of total*
Pullet . . .	29	13	45
2 years . .	22	12	54
3 years . .	3	0	0
Not recorded .	6	6	100

If next the age of the dam is considered in relation to the exhibition of constitutional vigour (Table 4), it is seen that approximately as many persistent birds were obtained from pullet-bred stock as from two-year olds. But those figures would perhaps bear a different interpretation if it could be shown that the mortality-rate amongst pullet-bred chicks differed considerably from that of birds bred from hens. From Table 5 it is obvious that in our stock this has not been a factor complicating the interpretation of the results.

TABLE 5

		At end of 3-year period	
Age of dam	*Number of birds*	*Number dead*	*Percentage dead*
Pullets . . .	29	9	31
2 years . . .	22	8	36
3 years . . .	3	1	33
Unrecorded . .	6	0	0
Totals . .	60	18	30

Having demonstrated suggestively, if not conclusively, that certain extraneous factors do not interfere to any appreciable extent with the occurrence of constitutional vigour in a stock, it remains to discuss the possibility of this desirable quality being inherited, and if so, to demonstrate the mode of its inheritance.

With regard to the latter, we have not as yet accumulated sufficient evidence, but some years ago breeding-experiments were initiated to

[1] Jull, Poultry Husbandry, McGraw Hill, New York and London, 1930.

determine whether constitutional vigour was inherited. This was suggested to us by the record of production of one of our hens hatched in 1928, who laid in successive years 210, 194, 193, 187, and 148 eggs. It will be appreciated that with this type of experimentation progress is necessarily slow, since all offspring must be kept for at least three years before it can be decided definitely whether they are carrying the quality desired or not.

We have at the present time about 30 birds closely related to the original dam, which are now of varying age, from one to three years. Of these, 6 birds are now in their third year of production and have given on the average 192 eggs in the pullet year, 189 in the second, and at present average 157 for the third year. As all these birds are still in full lay at the present time, it is expected that, with one exception, all will conform to our standard of vigour. If the condition were inherited, then it would be expected that inbred matings should produce progeny exhibiting a range of variation with regard to this quality. This has been found, and it is significant that out of 48 birds now in their second year of production individuals from this particular mating are well ahead of all others in regard to the number of eggs laid up to date.

From these observations there seems little doubt that the quality of constitutional vigour may be inherited, and the experiments now in progress should go far, it is hoped, to indicate the precise mode of its inheritance.

III. SOME ASPECTS OF POULTRY-NUTRITION

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With regard to nutrition Mr. Hamnett has stated what the poultry industry expects of the research worker. It is, in short, reliable guidance on the direction in which changes of rationing can be effected so as to maintain a low food-cost while at the same time maintaining the quantitative efficiency of the ration and the quality of the product, whether meat or eggs. In other words, he requires information to enable him to make his feeding-system a flexible one, so that he may not find himself tied to the use of a food that may be rapidly rising in price. The primary object of this paper is to indicate to what extent research workers have rendered this objective possible, and to postulate the direction in which further research work should go.

It may be as well, at the outset, to make clear the methods of attack available on nutritional problems. The first is what we may call, for the want of a better term, the short-range line of attack. This consists of field trials designed to answer a specific question of practical importance. In such trials groups of birds are submitted to a definite ration or series of rations and the results noted. Such trials have a definite appeal to the practical man, since they are readily understood by him, and the object of the tests is also readily comprehended. Their disadvantage lies in the fact that they are generally costly to carry out, and the answer when obtained can only be applied to the conditions under which the original

tests are carried out. In other words, they are inflexible in character, and the experimenter, as a general rule, can only tell the practical man that the results he has obtained will follow only if the rationing system and the management conditions of the test are rigidly adhered to in practice. Indeed, it often happens in such trials that management and other factors play such an important part in determining the results obtained, that results obtained in different parts of the country under varying conditions of management may contradict one another, in spite of the fact that the same system of rationing is carefully followed.

The second line of attack, and one that I must confess has always appealed to me, is the long-range method of attack. In this the object of the research worker is to establish the principles upon which practical feeding-systems should be based. Such methods are often, though not always, apparently divorced from practice, and it may be difficult on occasions for the practical man to see any connexion at all between the work the research worker is engaged upon and poultry-nutrition. It may, for instance, consist of a chemical investigation into the properties of a feeding-stuff, and may be carried out by a research worker with no knowledge whatever of poultry-keeping. If animals are used in the investigation, the poultry-keeper may find to his astonishment that rats or guinea pigs are used instead of poultry.

The difference between these two methods of attack will perhaps be better understood by an illustration. Let us imagine that the problem is the comparatively simple one of cheapening the fattening-ration, owing to the fact that the two commodities commonly used, Sussex ground oats and milk, have risen in price. In the short-range method of attack the worker makes out a list of cheaper substitutes, designs a series of rations using these substitutes, and tests these on flocks of birds. If success is achieved, the results are handed out to the industry. It will be noted, however, that such results are only of value to the industry while the prices operating for these substitutes at the time of the trial remain stable. If, however, the prices rise the practical man is again faced with his original problem, and the research worker has to start all over again with a new series of substitutes.

In the long-range method of approach, the research worker faces the problem from an entirely different angle. The questions he sets himself out to solve are:

1. To what extent is protein necessary in the fattening of birds?
2. What are the relative values of different feeding-stuffs for the production of fat in the bird?
3. What are the constituents of any given food that affect the quality of the carcass?
4. What are the quantitative relationships between the food eaten and the live-weight gain produced?

Such a method of approach appears at first sight to be unnecessarily tortuous, and it will be realized at once that much time must elapse before such workers have found the answers to all the questions they have set themselves. Indeed, the individual most directly concerned,

namely the practical poultry-keeper, may argue that, as he himself will probably be bankrupt or dead before any results of practical value to him emerge from such lines of attack, the long-range method is better left alone. I admit and sympathize with this line of reasoning; indeed, it is because of this possibility that I accept the view that there is a distinct place in any scheme of research for short-term experiments.

I should, however, like to emphasize that the view expressed above with regard to long-term research is unnecessarily pessimistic, since the research worker concerned, by careful planning of his work, can quickly obtain results of practical value. Thus, in the point at issue, I realized that if I could answer the first question set out above, i.e. the extent to which protein is necessary in fattening, I might be able to cheapen the fattening-ration considerably, since the protein of the ration formed the expensive ingredient. This I did, and found that the amount of protein used in fattening-rations could be materially reduced without adversely affecting either the rate of fattening or the quality of the product. In order to place these laboratory results beyond doubt, the Wye Table Poultry Committee carried out trials under commercial conditions on a large number of birds, and found that the amount of milk used in a fattening-ration could be halved and still yield just as good results as those obtained on the more expensive ration.

Similarly, the results obtained by Miss Cruickshank in her studies on the physiology of fat-metabolism of the fowl enabled us to predict with confidence that a vegetable fat, palm oil, could be used effectively as a substitute for mutton fat in cramming mixtures. Since palm oil was cheaper than mutton fat, and also a more pleasant material to handle, this fact was of importance to the industry, and here again commercial trials at Wye substantiated our views.

These two results will, I think, demonstrate that the long-term method of research is capable of producing results within reasonable time that are of direct practical benefit. The main advantage, however, of the pursuit of the principles underlying poultry nutrition that this method of research entails, is that the workers concerned accumulate knowledge which enables them to predict what will be the likely result of any particular change of ration. They are consequently often in the position of being able to give direct help in the way of advice to poultry-keepers on the nutritional problems that so often beset them, without having to test the advice experimentally before giving it.

It is, however, essential that the practical poultry-keeper should realize the magnitude of the task he sets the research worker when he tells him that all he requires is a flexible feeding-system that will enable him with confidence to alter his rations at will. At the risk of making him disheartened, I might with advantage indicate the facts we require about every poultry feeding-stuff to render this possible. They are:

1. A knowledge of the quantitative relationships between the protein in the feeding-stuff and the protein produced in the product, whether meat or eggs.
2. The same knowledge with regard to the energy of the feeding-stuff and the energy of the product.

3. A knowledge of the chemical make-up of each protein, so that we can assess its biological value for the purpose for which it is used.
4. The behaviour of the feeding-stuff, whether fed alone or in combination with other feeding-stuffs, from the standpoint of palatability.
5. The nature and extent of the mineral substances of value to the bird present in the feeding-stuff.
6. The nature and extent of the vitamins present in the feeding-stuff.
7. The effect of the feeding-stuff in question on the quality of the product produced.

The extent to which our knowledge is lacking in these respects can be estimated by considering the views held by those interested on the value of some of the commonly used feeding-stuffs. Take bran, for instance. This food is highly esteemed as a feeding-stuff, and is used in considerable quantities by poultry-keepers, although, from the point of view of its digestible nutrients, it is a relatively dear product compared with other wheat by-products. Moreover, chicks have been successfully reared on rations from which bran has been omitted. What then, are the properties belonging to bran that makes it such a favourite food with poultry-keepers, and how can we render ourselves independent of the use of this food if necessity demands?

Again, take maize. The Americans have shown that maize can be included in poultry mashes to a very great extent and yield very good results. Yet in Britain there has grown up among the poultry-keepers an objection to its use in large quantity. Now since maize is one of the cheapest feeding-stuffs available, it is essential that the reason for this objection to its use should be explored and the true position of maize as an ingredient of poultry rations be established.

Again, there is considerable doubt among poultry-keepers and others as to the extent to which it is necessary to include protein in the rations of laying fowls. Since foods of a protein nature form the most expensive part of the ration, the necessity for clearing up this point is obvious. It may be desirable to mention, however, that under certain conditions it may be necessary to include a more generous allowance of protein than the minimum requirements indicate. Thus, it has been shown that rats fed on a cereal diet rich in fat, develop fatty livers, whereas if the diet contains liberal amounts of certain proteins this fatty condition of the liver does not develop. Now we know that birds are prone to develop fatty livers on certain cereal diets, to what extent then would the inclusion of protein in the diet counteract this tendency?

The facts I have given clearly indicate the need for further research. In what direction can this research be most usefully guided?

Our present knowledge enables us to construct suitable rations for any purpose required, that is, from the qualitative standpoint. We can ensure that the ration contains a protein of good biological value, all the vitamins needed, and also the mineral requirements. From the quantitative standpoint, however, we are much less certain, and in my

opinion many rations break down in practice owing to lack of this knowledge. Particularly is this the case now, owing to the growth of *ad lib.* feeding-systems, since if the ration is excessively rich or poor either in protein or energy, bad results may ensue. Birds are reared and kept under so many different systems of management that it is obvious that a ration suitable for one system will be unsuitable for another. Reflection shows that the principal difference between these systems, apart from the variability of access to fresh air and sunshine and natural food, is the very variable opportunities for exercise these systems afford. As opportunity for exercise diminishes, the energy requirements for maintenance decrease. Consequently, the chief need of research at the present time lies in the necessity for obtaining an accurate measure of the protein and energy requirements of chicks and fowls kept under these different conditions, and of the protein and energy yielded by the commoner feeding-stuffs.

With this knowledge in our possession, we should be in the position of being able, not only to draw up a suitable dietary for any system of management, but also to indicate changes in the ingredients of the rations should economic necessity demand. The difference of opinion that exists among poultry-keepers as to the extent to which bran and maize should be used in poultry-rations is in all probability largely due to the relative extent to which these substances yield energy to the body, correlated with the varying amounts of energy that the animal requires under different systems of management.

In conclusion, we may perhaps usefully consider the relation of nutrition to disease, since disease, unfortunately, takes a constant toll of many of our poultry flocks, and in certain cases has been responsible for the failure of poultry enterprises. There is some evidence that resistance to certain diseases is most marked in well-nourished individuals. Good nourishment, therefore, may aid us to a certain extent in keeping our flocks healthy, but it is as well for us to realize that nourishment can only help us here to a limited extent. Certain diseases and abnormalities considered in the past to be due to disease organisms have since been shown to be conditions of malnutrition due to vitamin or mineral deficiencies. Such conditions we can avoid by correct feeding. Certain others, causing ill health or unthriftiness, are due to disease organisms which debilitate the animal without necessarily causing death. By using a biologically complete diet, or by the use of certain foods, it has been found possible to control to a large extent the harmful effects these organisms produce, instances of such control having been established in the case of coccidiosis and round-worm infestation. A large number of diseases, however, are caused by organisms which attack well-nourished and badly nourished individuals alike; in these cases dietary can obviously have little effect. The necessity for research in poultry-diseases has been stressed recently both by Government commissions and research advisory bodies. It is as well, therefore, for us to realize that only to a very limited extent is a study of the relation of nutrition to disease likely to yield fruitful results.

IV. THE ECONOMIC AND DISEASE ASPECTS OF PARASITIC WORM-INFESTATION IN POULTRY

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Introductory.—It is probably as a result of the modern artificial methods of rearing poultry that disease has become such an acute problem to the poultry-farmer. Its influence is to be seen in all poultry-farming activities, in the construction of houses and pens, in the limitation of the number of fowls which may be kept on a given area, and in the large amount of labour which must be expended on hygiene. Even the scientific breeding and feeding of poultry, as dictated by specialists in genetics and nutrition, is in no small degree an attempt to resist and control disease the more successfully. Disease must, in fact, be regarded as one of the principal agents controlling development of the poultry industry.

In this short note is discussed the particular position of parasitic worms in the development of poultry farming. These parasites are widely distributed and appear to be on the increase, so that to understand their possible influence upon the growth, health, and productivity of poultry is of some importance.

It is a subject on which there is considerable diversity of opinion; poultry farmers in general, and some of the workers in the various centres where post-mortem examinations are carried out for the diagnosis of poultry disease, hold strongly to the view that parasitic worms of any and every kind are essentially harmful. Reference has repeatedly been made in the technical press to the very harmful results of worm-infestation, the caecum worm having received specific mention. That there is a marked difference of opinion, however, is clearly illustrated in a comparison of the reports of different centres for the diagnosis of disease among poultry by routine post-mortem examinations. For example, a report from the National Poultry Institute states that some 31 per cent. of the fowls from egg-laying trials died as a result of infestation with parasitic worms, but reports on similar post-mortem work carried out at the Ministry of Agriculture's Veterinary Laboratory at Weybridge show that only 0·5–4·9 per cent. of fowls in 20 county egg-laying trials, over a number of years, are regarded there as having died of parasitic worms. Space does not permit any further account of this difference of opinion among specialists in poultry disease, but considerable evidence of it is to be found in the literature, and one is led to ask what are the reasons underlying this difference of opinion?

The text-books on parasitology show that some 150 or 200 different species of parasitic worms are known to occur in the different kinds of domestic fowls (excluding game birds). Of this formidable list, however, only a dozen or so may be regarded as of common occurrence in Great Britain, and only two as frequently associated with acute disease, namely *Syngamus trachea* (the gapeworm of chickens) and *Amidostomum anseris* (the gizzard worm of geese).

It is obvious that different species of parasitic worms have very different actions upon their hosts, so that it will be convenient to divide them into two classes, those which are definitely associated with disease and those which are not—'definite pathogens' and 'indefinite pathogens'.

Definite pathogens.—In 1928 an American research worker named Cram published a paper describing the symptoms and gross lesions caused by the presence of certain species of the definitely pathogenic worms of poultry, and no one could doubt the importance of these particular parasites to the health of an infested flock of fowls. It is obvious that the poultry farmer should be prepared to go to almost any length to prevent the increase of such parasites as these by vigorous hygienic measures, or by alterations in his system of farming; or in attempts at eradication by the use of expensive drugs for the expulsion of the worms, even though the use of drugs may be attended by a certain amount of danger to the fowls.

Gapes in chickens and gizzard-worm disease in goslings, the two definite worm diseases already referred to as occurring in Britain, are fatal diseases and call for the most rigorous treatment by such methods as have just been mentioned. We do not hear very much about either of them at the present time, because on the one hand geese are not very plentiful, and, on the other hand, the modern intensive system of rearing chickens is a sure preventive of gapeworm-infestation. There is, however, a tendency in some quarters to revert to extensive methods of rearing chickens in the open, with a view to warding off certain diseases of adult life, and it is not unlikely that, should this become a general practice, gapes will become one of the major disease problems of the poultry-breeder.

Indefinite pathogens.—The position with regard to the indefinite pathogens is not so easily defined, and this group is our principal difficulty in assessing the importance of parasitic worms to the poultry industry.

Of the several worms belonging to this group which commonly occur in domestic poultry in Great Britain, I would single out four for special consideration: the 'caecum worm' (*Heterakis gallinae*), the 'round worm' (*Ascaridia lineata*), the 'thread worm' (*Capillaria longicollis* and allied species in the small intestine), and a certain minute tapeworm (*Davainea proglottina*).

These four species are so widely distributed as to be represented on almost every poultry farm of any size in Great Britain and, indeed, throughout the world; and it is principally over these species that differing opinions range as regards disease-production.

In the interpretation of post-mortem findings a few inexperienced observers might consider that an infestation of one or two individual large worms, such as the round worm, *Ascaridia lineata*, is capable of causing a disturbance in health; other observers go to the opposite extreme and argue that even heavy infestations exert no unfavourable influence; but it seems reasonable to suppose that, although a few parasitic worms may cause no real harm, a heavy infestation very probably would do so, and the *extent* of the infestation must be regarded as of first importance in deciding whether disease will result or not.

As yet, however, we have very few data to guide us in the diagnosis of disease caused by these worms, and one of the tasks with which the research worker is faced is to determine the extent of infestation that constitutes the border-line of pathogenicity for each species.

Diagnosis of pathogenicity.—A certain amount of work has already been carried out on this point, principally by Ackert and co-workers in America, where a series of observations has been made on the relationships between the round worm, *Ascaridia lineata*, and its chicken host.

It was found that experimental chickens became visibly affected about 12 days after receiving a dose of 1,000 embryonated worm's eggs, on the fourteenth day several of them died, and the growth of the survivors was almost completely inhibited up to the seventeenth day. During the next few weeks the infection was completely eliminated, however, and the experimental chickens grew into perfectly normal fowls.

When applied to poultry-farming conditions and the question of the economic importance of this parasite, these results are open to the criticism that the administration of the infection in one large dose instead of numerous small ones is unnatural and might be expected to produce an unnatural disease-condition. Some of the work has therefore been repeated at Weybridge with the difference that several small doses were given instead of one large one. Half of the experimental chickens, which were divided into batches of 50, received a well-balanced ration and others were fed on a very badly balanced ration, to ascertain whether nutrition might have an influence on susceptibility to these parasitic worms. It was found that more than twice as many worms developed in the chickens fed on the badly balanced ration as developed in those fed on the well-balanced ration, the average worm-content being 26·6 and 11·6 worms per chicken, respectively. It was quite clear, however, as judged by the weekly weights of the chickens, that an average of 11·6 worms per chicken was not sufficient to interfere with growth, and an average of 26·6 worms per chicken affected growth only very slightly, if at all. These results appear to indicate that although sudden heavy infestations may cause death, as shown by Ackert, low-grade infestations are of little or no significance to the health of the chicken.

A similar experiment was attempted with *Capillaria.* Infective material being more difficult to obtain in this instance the observations had to be limited to a small group of chickens. Infestations ranging from zero up to 420 worms per chicken were obtained in the experimental groups of 18 birds, and there appeared to be some correlation between infestation and gain in weight, but only when the infestation exceeded 200 worms per chicken.

The small tapeworm, *Davainea proglottina*, was put to the same kind of test by Taylor in 1933. Snails carrying the intermediate stages were fed to some experimental chickens, but although an infestation of nearly 4,000 worms was produced in some of the chickens, no disturbance of health appeared to result therefrom, nor was there any effect upon the rate of growth of the chickens.

The results obtained by other workers on experimental infections of the caecum worm are peculiar in that it appears to be impossible to

produce a heavy infection in a healthy chicken. Some special immunity mechanism comes into play which will allow only a few worms to develop. It seems highly probable, therefore, that this most common of all parasitic worms of poultry is of little economic importance, heavy infestations apparently being able to develop only after some other diseased condition has already broken down the immunity.

Conclusions.—Although the experimental evidence on the pathogenicity of these worms must be considered too meagre to permit us to draw definite conclusions, it strongly suggests that the ordinary low-grade infestation with these indefinitely pathogenic worms is not so harmful as some observers of poultry disease consider it to be. In the absence of more satisfactory data I should be among the last to conclude that the common parasitic worms of poultry are of no consequence, and only wish to show that too much stress may have been laid on the importance of disease-production by these agents.

Many more experimental data along the lines of that already mentioned must be collected before we shall be able to determine disease-causation by the presence of these parasites, and an investigation must also be made into the possible association of parasitic worms with bacterial and virus diseases, and into the question of multiple parasitism. This last-mentioned condition is often seen in intensively reared chickens a few weeks after they have been placed in open runs, when an infestation of coccidia and worms of more than one kind is often seen in the same chicken, and is thought by some observers to be a cause of very severe loss.

Treatment.—Meanwhile we may ask how far it is worth while instituting wholesale medicinal treatment on the poultry-farm; or making drastic alterations in the methods of rearing in order to avoid the risk of worm disease?

Some interesting observations on this point have been made by the American workers Bleecker and Smith (1933) and by Thomas (1933), who compared the egg-production of flocks receiving regular worm-treatment with that of flocks receiving no treatment. At the end of each of these separate series of observations it was concluded that medicinal treatment was of no material value, by way of increasing the egg-production, &c., and in one instance that it caused actual harm.

The reasonable explanation to offer for these results seems to be that the worm-infestation of the test flocks was not at a high enough level to cause disease, so that the poisonous drugs administered for the expulsion of the worms were more harmful to the health of the fowls than were the few worms which were present.

All drugs which are really effective for the expulsion of parasitic worms are essentially poisonous, and the dosage must be so carefully judged that the worms are killed and the fowls injured as little as possible. Wholesale treatment for parasitic worms should not, therefore, be taken up unless the existence of harmful parasitism has been determined with tolerable certainty.

Without doubt our safest attitude is to regard all parasites as potentially harmful. Eradication should be our ultimate object; but the most

reasonable line to take in the present state of our knowledge is the institution of strict sanitary measures, and the ordering of poultry management in such a way that parasitic worm-infestation may be kept below the minimum requisite for disease-production.

Summary.—In summarizing it may be said that the definitely pathogenic parasitic worms, represented in this country by the gapeworm of chickens and the gizzard worm of geese, are, at the present time, causing comparatively little trouble. A few species which are not definitely pathogenic, often occurring in healthy birds, are widely distributed; as yet we know very little of their importance to the poultry industry and, on post-mortem examination, are unable to say whether the number present is sufficient to cause disease or not. What little work has been done suggests, however, that although heavy infestations may cause disease, light or moderate infestations do not, and the treatment of whole flocks, using expensive and dangerous drugs for the expulsion of parasitic worms, is not warranted unless an unusually heavy infestation has been shown to be present. Until better experimental evidence is forthcoming on the disease-producing propensities of the common parasitic worms, and on the significance of multiple parasitism, the economic importance of these widely distributed parasites to the poultry industry will remain a matter of conjecture.

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THE RESPONSE OF GRASSES AND CLOVER TO TREATMENT ON ACIDIC UPLAND SOILS, AND THE EFFECT OF HERBAGE PLANTS ON THE REACTION OF ACIDIC SOILS

Pt. III. A COMPARISON OF THE PRODUCE OF *MOLINIA* AND FESCUE SOILS

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Some of the critical experiments conducted by the Welsh Plant-Breeding Station on the improvement of hill-grazing have now been in progress for several years. In a previous issue of this *Journal* a preliminary account has been given of one of these experiments which was begun on the Plynlymon area in 1931. Its main object is to study a combination of treatments for increasing the yield of those nutrients in which the natural herbage is notoriously deficient. With this purpose in view the soil was subjected to cultivation, manuring, and the sowing of cultivated grasses and wild white clover, the operations being carried out both separately and jointly. A total of 20 different treatments were triplicated on small plots 4 sq. yds. in area, and the nature of these treatments has already been described in detail [1]. Exactly the same treatments were applied both to *Molinia* and fescue soils, but up to the present the discussion of the results has been limited to the former soil, and it has been shown that the combined treatments effected a profound increase in the nutrients of the herbage. The additional data now derived from the experiment enable us to consider the results from a wider angle, and afford a basis for comparing the productivity of the *Molinia* and fescue soils under varying circumstances.

It should be explained that the two soils chosen for this experiment are good examples of the fluctuating soil conditions encountered on the Welsh sheep-walks. It is true that both soils are similar in their poverty of nitrogen and minerals, but they show marked differences in other important characteristics. The *Molinia* soil overlying clay is defectively drained, and has no shelter from the cold winds. The fescue soil is shallow, lies over stones and rock, and the adjacent slopes afford shelter from the north-east and east winds. These dissimilar conditions have a bearing on the yields of dry matter obtained from the unsown plots of the two soils (Table 1).

The yields shown in Table 1 were obtained as a result of taking three cuts during each growing-season in 1932 and 1933, and four cuts during subsequent seasons. The higher yields obtained from the fescue soil are largely due to the greater power to withstand the cutting possessed by the natural vegetation on this soil. The herbage on the *Molinia* control plot (T), although it had received no cultivation or manurial treatment,

changed, as a result of cutting, from a *Molinia* type into a herbage predominated by fescue. This transformation was practically complete by the end of 1934. The difference in yields from the *Molinia* and fescue soils in 1935 reflects the fact that the *Molinia* soil suffered from excess moisture, and the botanical analysis shows that a much higher bent-fescue ratio was forthcoming in the drier fescue soil. The wide difference in yield from those plots which were cultivated but not manured (K) is

TABLE 1. *Yield of Dry Matter from Unsown Plots on* Molinia *and Fescue Soils. Seasons 1932–5 (grams per plot)*

Treatment	*Soil*	*1932*	*1933*	*1934*	*1935*	*Mean*	*Yield from fescue (Molinia = 100)*
Control (T)	*Molinia*	668	124	107	132	258	100
	Fescue	686	375	191	150	351	136
Manuring only (R)	*Molinia*	863	318	387	189	439	100
	Fescue	831	513	479	289	528	120
Cultivation only (K)	*Molinia*	331	335	107	189	241	100
	Fescue	384	499	212	274	343	142
Manuring and cultivation (Q)	*Molinia*	1,021	581	235	194	508	100
	Fescue	1,222	741	235	392	648	128

also to be largely attributed to the better drainage in the fescue area. In those plots that have either been manured (R) or both manured and cultivated (Q) (though the yield from the fescue soil is still greater than that from the *Molinia*) it is clear that the difference between the relative yields of the two areas is not so marked. This shows that the manuring has had a greater effect on the *Molinia* produce than on that of the fescue. One noteworthy result of the manures is the manner in which they accelerated the transformation of the herbage from that of a *Molinia* type to that of a fescue. This conversion has been previously shown to occur rapidly as a result of frequent defoliation coupled with liberal manuring [2]. Manuring of the *Molinia* soil has also produced a marked increase in the bent-fescue ratio. In the next table the yield of chemical constituents obtained from the unsown plots of the two soils is shown.

TABLE 2. *Total Yield of Nitrogen, Lime, and Phosphate from Unsown Plots on* Molinia *and Fescue Soils. Seasons 1932–5 (yield in grams per plot)*

	Nitrogen		*Lime*		*Phosphate*	
Treatment	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
Control (T)	20·17	25·02	4·04	6·61	3·03	4·40
Cultivation only (K)	20·18	26·99	4·54	6·28	2·84	3·61
Manuring only (R)	39·25	41·06	10·43	13·96	8·35	11·85
Manuring and cultivation	41·00	45·14	12·01	18·34	10·41	13·93

The above table shows that a greater yield of chemical constituents is obtained from the unsown plots of the fescue soil. This is true not only when the soils are untreated, but also when they are manured, or cultivated, or subjected to both these treatments. Both soils are seen to

give a marked response to manuring, but a negligible response to the process of cultivation by itself. It is evident that cultivation unaccompanied by manuring has but little effect in converting the reserve supplies of insoluble nutrients that are present into an available form. Manuring has had a pronounced effect on the yield of all constituents in both areas. The effect of manures in those areas where cultivation was also resorted to is seen to be greater than in the uncultivated plots, and the significance of this becomes greater when it is borne in mind that the cultivation initially involved a drastic destruction of vegetation, and therefore a curtailment of yield during the first season.

The results show conclusively that the natural vegetation on both soils is amenable to change and improvement, but that this improvement is confined within the somewhat narrow limits set by the native plants themselves. When bearing its own vegetation, the fescue soil fares better than the *Molinia*, owing no doubt to the transpiration rate of the natural herbage on the *Molinia* area being too slow to eliminate the surplus water, with the result that air-supply for the root-system becomes a frequent limiting factor. The question therefore arises: how would these two soils compare when growing a kind of vegetation which would afford a higher transpiration rate? The behaviour of a mixture of perennial rye-grass, cocksfoot, and wild white clover on the two soils answers this question. This mixture was sown under different manurial treatments in cultivated plots on the *Molinia* and fescue areas in the spring of 1931, and the dry-matter yields obtained for the four subsequent harvest years are shown in Table 3.

The Effect of introducing Cultivated Grasses and Wild White Clover on Molinia *and Fescue Soils*

A comparison of the highest mean yields in Table 3 with those in Table 1 shows that the introduction of cultivated grasses and clover has resulted in an increased yield of dry matter over the period under review.

TABLE 3. *Yield of Dry Matter (grams per plot) from Cultivated Grasses and Wild White Clover in* Molinia *and Fescue Soils. Seasons 1932–5*

Treatment per acre	*Soil*	*1932*	*1933*	*1934*	*1935*	*Mean*	*Yield from fescue (Molinia = 100)*
12 cwt. basic slag (P)	*Molinia*	1,162	740	240	412	639	100
	Fescue	1,025	773	292	472	641	100
12 cwt. basic slag + 10 cwt. limestone (A)	*Molinia*	1,309	851	290	695	786	100
	Fescue	1,380	748	419	589	784	100
12 cwt. basic slag + 1 ton limestone (C)	*Molinia*	1,472	884	340	715	853	100
	Fescue	1,573	760	312	436	770	90
12 cwt. basic slag + 30 cwt. limestone (B)	*Molinia*	1,376	941	395	811	881	100
	Fescue	1,349	803	453	680	821	93
12 cwt. basic slag + 1 ton limestone + 1½ cwt. potash (D)	*Molinia*	1,535	943	278	710	867	100
	Fescue	1,574	794	407	469	811	94
Same as (D) + 2 cwt. nitro-chalk (E)	*Molinia*	1,503	879	375	712	867	100
	Fescue	1,617	659	387	598	815	94
Same as (D) + 1 ton limestone + 5 cwt. nitro-chalk (G)	*Molinia*	1,065	1,044	539	794	861	100
	Fescue	1,324	611	384	526	711	82
12 cwt. basic slag + 10 cwt. nitro-chalk (L)	*Molinia*	1,113	693	392	320	630	100
	Fescue	1,279	776	380	481	728	116

In addition, the relative yielding capacity of the *Molinia* and fescue soils has been altered: whereas a higher yield was previously obtained from the unsown plots of the fescue soil (Table 1), with the presence of cultivated grasses and clover the dry matter from the *Molinia* plots may be equal to or even exceed that from the fescue (Table 3). There is one exception, namely, where the manures employed were basic slag and a heavy dressing of nitro-chalk (L). In this case a higher mean yield was derived from the fescue soil. The manurial treatment in this particular instance included such a heavy increment of nitro-chalk as practically to eliminate wild white clover as a contributor to the herbage. The important contribution of wild white clover to the dry matter of the herbage, particularly on the *Molinia* soil, is clearly brought out by the low yield obtained under this treatment as compared with the higher yields derived under the other treatments favourable to clover development. Where, however, basic slag was used, either alone or in conjunction with a small quantity of limestone, the yield from the *Molinia* soil equalled that from the fescue. Where limestone to the extent of 1 ton per acre or over was included in the manurial dressing, the average yield from the *Molinia* plots slightly exceeded that from the fescue.

The difference in behaviour between the unsown and sown plots indicates that when a new type of vegetation is introduced into these upland soils a whole series of new factors comes into play that entirely alters the performance of the soils in question. The increased dry matter given by the cultivated grasses and clover points to increased transpiration, which provides a means of eliminating some of the excess water that previously restricted the aeration in the *Molinia* soil. On the other hand, even under low-yielding conditions, water-supply is at times a limiting factor in the fescue soil, and consequently the higher the yield-level attained as a result of joint cultivating, manuring, and seeding, the more likely is the yield from the *Molinia* soil to exceed that from the fescue.

In the following table the yields of nitrogen and minerals from the cultivated grasses and clovers grown on the two soils are given:

TABLE 4. *Total Yields of Nitrogen, Lime, and Phosphate from Cultivated Grasses and Wild White Clover in* Molinia *and Fescue Soils (grams per plot). Seasons 1932–5*

Treatment per acre	*Nitrogen*		*Lime*		*Phosphate*	
	Molinia	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
12 cwt. basic slag (P)	55·95	53·89	21·42	21·85	15·21	14·64
12 cwt. basic slag+10 cwt. limestone (A)	74·97	74·29	34·15	29·75	17·89	17·51
12 cwt. basic slag+1 ton limestone (C)	83·79	63·08	38·43	31·53	20·29	16·71
12 cwt. basic slag+30 cwt. limestone (B)	88·34	72·91	40·72	35·31	20·50	17·65
12 cwt. basic slag+1 ton limestone+1½ cwt. sulphate of potash (D)	83·73	70·28	41·58	33·42	20·03	17·23
Same as (D)+2 cwt. nitro-chalk (E)	82·52	71·50	45·40	37·34	19·94	17·44
Same as (D)+1 ton limestone+5 cwt. nitro-chalk (G)	76·35	53·01	34·52	30·19	19·04	15·94
12 cwt. basic slag+10 cwt. nitro-chalk (L)	56·26	61·16	23·84	27·99	15·97	16·50

The introduction of cultivated grasses and clover has resulted in a much higher yield of nitrogen, lime, and phosphate than obtained from the unsown plots (Table 2). Where 10 cwt. limestone has been applied

in addition to 12 cwt. basic slag the yield of all three constituents has improved in both areas. With increasing quantities of limestone an increased lime-yield is forthcoming from the produce of the two soils. In the fescue soil no further improvement in the yields of nitrogen and phosphate occurs on increasing the 10 cwt. limestone dressing. In the *Molinia* soil, on the other hand, the nitrogen and phosphate recovered in the herbage increase as a result of increasing the limestone dressing from 10 cwt. to 20 cwt.; by further increasing the limestone to 30 cwt. the yield of nitrogen is again raised, but that of phosphate not significantly.

The Difference in Response to Limestone from Molinia *and Fescue Soils*

It is seen from Table 4 that the chemical constituents yielded by the cultivated grasses and clover on the *Molinia* soil may be as much as or greater than those on the fescue soil. As a result of applying 12 cwt. basic slag the yields of all constituents are practically the same from both areas, but where 1 ton of limestone has been applied with the slag, higher yields are forthcoming from the *Molinia* soil. This is made clear by the following figures, the yields of all constituents from the *Molinia* soil obtained as a result of applying slag only being taken as 100:

	Dry matter		*Nitrogen*		*Lime*		*Phosphate*	
Treatment per acre	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
12 cwt. basic slag	100	100	100	96	100	102	100	96
12 cwt. basic slag + 1 ton limestone	133	121	150	113	179	147	133	110

The above comparison shows that a higher return of all constituents is obtained from the limestone on the *Molinia* soil than on the fescue, the difference being greatest for yields of nitrogen and lime. It is probable that more than one cause may contribute towards this result. The possibility of water-supply being more often a limiting factor on the fescue soil as higher yield-levels are attained has already been mentioned. Apart from this, heavier dressings of limestone on the more acid and more heavily buffered *Molinia* soil may produce more beneficial effects than on the fescue soil. A further possibility which would account for a greater response to limestone on the *Molinia* soil is a greater amount of leaching from the fescue soil. The importance of this last factor is made clear from a study of the response of the two soils to different dressings of limestone during successive years. Table 5 gives the percentage increase in plant lime as a result of supplementing a basal dressing of 12 cwt. slag with varying quantities of limestone.

Table 5 shows that where small increments of limestone amounting to 5 or 10 cwt. have been added to basic slag, a greater response has been given during the season of application by the plants on the fescue soil. During subsequent seasons, however, a greater response is invariably obtained in the *Molinia* plots. By the third season, although an appreciable response is still obtained from the *Molinia* soil, the

response from the fescue soil is negligible. Where dressings of 20 cwt. limestone are applied a greater response is sometimes, but not always, obtained from the fescue soil during the season of application. The response from the fescue soil diminishes at a more rapid rate than that from the *Molinia*, with the consequence that a considerable response is still obtained during the fifth season after application in the *Molinia* soil, but none in the fescue soil. During the exceptionally dry season of 1933, when only 9·87 in. of rain fell from April to September, no response was forthcoming from the fescue soil where 20 cwt. of limestone had been applied in 1931, and where the figures for 1934 indicate that at any

TABLE 5. *Percentage Increase in Yield of Plant Lime as a Result of supplementing 12 cwt. of Basic Slag with Various Quantities of Limestone*

Series and treatment	*1931*		*1932*		*1933*		*1934*		*1935*		*Percentage increase for five seasons*	
	Molinia	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
A. 5 cwt. limestone applied in 1931+5 cwt. in 1934 .	51	134	65	48	37	nil	61	85	79	39	63	42
B. 10 cwt. limestone in 1931+20 cwt. in 1934 . .	121	248	81	61	59	6	145	189	129	68	91	71
C. 20 cwt. limestone in 1931 .	420	379	107	111	36	nil	61	13	91	1	93	62
D. 20 cwt. limestone (+potash) in 1931	360	469	120	126	88	nil	23	44	81	nil	106	75
E. 20 cwt. limestone (+potash and nitro-chalk) in 1931+20 cwt. limestone (+ammonium nitrate) in 1934 .	720	3·50	154	126	52	nil	136	117	97	70	137	86
Rainfall (April–September) .			19·96		9·87		18·35		23·55			

rate some calcium from the limestone was left in the fescue soil. These results show that with adequate rainfall the initial response of the fescue area to limestone is as great as that of the *Molinia*. They make clear that water-supply is a very important factor, and that under dry conditions the plants in the fescue soil fail to take advantage of the lime increments. The results further point to a more rapid leaching of the limestone from the fescue soil than from the *Molinia* soil. Some of the other factors already referred to may also contribute towards the difference in response to limestone between the *Molinia* and fescue soils. The net result is that over a number of years the recovery of lime from limestone, when the latter is applied as a supplementary dressing to basic slag, is greater in the *Molinia* than in the fescue soils. This result is the same whether the limestone be applied alone or in conjunction with other manures. When other manures are applied with the limestone, the response in plant lime is more marked in both areas. Thus the response is somewhat more pronounced where potash is included in the dressing, and still greater where both potash and nitrogen are added.

Factors influencing the Recovery of Phosphate from Basic Slag applied to Molinia *and Fescue Soils*

One of the most important questions relating to the economy of hill pastures is the efficiency with which phosphate applied to the soil is recovered in the plant. A speedy recovery of phosphate lessens the losses

through leaching which have been shown by Robinson to occur in these soils [3]. It is also of the highest importance from a nutritional standpoint to raise the phosphorus status of the herbage while maintaining the high calcium that is ensured by the presence of wild white clover. In Table 6 the quantity of phosphate recovered from the basic slag applied to the two soils under consideration is given.

TABLE 6. *The Recovery of Phosphate from High-soluble Basic Slag when applied to a Mixture of Cultivated Grasses and Wild White Clover on Welsh Upland Soils. (Total for Seasons 1931–5.) (Grams per plot)*

Treatment per acre	*Phosphate in manure*	*Phosphate recovered in herbage*		*Per cent. phosphate from manure recovered in herbage*	
		Molinia	*Fescue*	*Molinia*	*Fescue*
12 cwt. basic slag (P)	75·5	12·94	12·23	17·1	16·2
12 cwt. basic slag + 10 cwt. limestone (A)	,,	15·85	16·51	21·0	21·9
12 cwt. basic slag + 1 ton limestone (C)	,,	19·79	16·61	26·2	22·0
12 cwt. basic slag + 30 cwt. limestone (B)	,,	18·76	16·75	24.8	22·2
12 cwt. basic slag + 1 ton limestone + 1½ cwt. sulphate of potash (D)	,,	19·05	16·71	25·2	22·1
Same as D + 2 cwt. nitro-chalk (E)	,,	20·12	17·86	26·7	23·7
Same as D + 1 ton limestone + 5 cwt. nitro-chalk (G)	,,	18·17	17·47	24·1	23·1
12 cwt. basic slag + 10 cwt. nitro-chalk (L)	,,	15·90	16·04	21·1	21·2

Where basic slag alone was applied to the soil, the recovery of phosphate shown in Table 6 is in close agreement with that obtained from acid soils in the grassland experiments conducted for four years by the Permanent Committee on Basic Slag [4]. In these experiments, which were carried out at different centres, a mean recovery of 17 per cent. was obtained from high-soluble slag in the acid soils examined, although wide variations were naturally encountered, depending on the soil and on the frequency of cutting the herbage. It is evident from Table 6 that a very important factor in the recovery of phosphate from basic slag in Welsh upland soils is the effect of limestone on this recovery.

Where 1 ton of limestone has been applied to the *Molinia* soil the percentage recovery for the period 1931–5 has been raised from 17·1 to 26·2 per cent. Higher increments of limestone did not further improve the phosphate recovery. In the fescue soil practically as good a recovery was obtained from 10 cwt. limestone as from higher quantities, this small application of limestone raising the phosphate recovery from 16·2 to 21·9 per cent. It is seen that the potash in conjunction with limestone did not improve the phosphate recovery, but nitro-chalk when added to the limestone and potash did bring about a slight improvement. The effect of adding 10 cwt. nitro-chalk to the basic slag produced a similar effect on the phosphate recovery to that obtained from 10 cwt. limestone.

The improvement effected by very small quantities of limestone, not only on the dry matter and protein but also on the plant calcium and phosphorus, undoubtedly justifies the inclusion of a small amount of limestone as a constituent of the basal dressings to be applied to these hill areas. A better response to limestone is obtained from the *Molinia* than from the fescue soil, because the effect of the limestone is more lasting on the *Molinia* soil.

Relative Significance of Basic Slag and Limestone in the Manuring of Upland Areas

Whereas a liberal dressing of slag supplemented with limestone gives very satisfactory manurial conditions for establishing cultivated grasses and clover, the effect on the establishment of using only a little slag must also be considered. To throw light on the relative significance of basic slag and limestone in the manuring of these areas, a pot experiment was carried out in 1934 and 1935 in which the *Molinia* soil was subjected to the following treatments:

Series A. Manuring equivalent to 12 cwt. 8 per cent. basic slag per acre.
Series B. Manured as above plus 30 cwt. limestone.
Series C. 2 cwt. 8 per cent. basic slag plus 6 cwt. limestone.
Series D. Manured as above plus 36 cwt. limestone.

Thus in Series A and B a moderate dressing of basic slag was included; in Series C and D very little slag but limestone to supply the same quantity of total calcium as in A and B respectively. Of the six pots included in each treatment, three were given periodical dressings of ammonium nitrate, and the other three received no nitrogen. In Series C and D small periodic dressings of monocalcic phosphate were given to the soil in order to bring up the phosphate supply gradually to the level of A and B; they were applied immediately after each cut. Table 7 gives the dry-matter yields from the grass, namely, red fescue, grown in the pots.

The results shown in Table 7 demonstrate the importance of a good initial dressing of phosphate for satisfactory establishment. Under the conditions of this experiment the first cut of grass from the low phosphate application (C) amounted to only 17 per cent. of that obtained from the higher phosphate dressing (A). Where the low phosphate was supplemented with 36 cwt. of limestone (D), although a marked improvement was effected in the yield, it was still lower than that obtained from the higher phosphate dressing without limestone (A), and much lower than that obtained from the higher phosphate dressing in conjunction with limestone (B). The application of available phosphates in small increments rapidly brought about an improvement, so that by the end of 1934 the yields from Series C and D compared favourably with those from A and B, and in 1935 exceeded them. The total yield of dry matter obtained was, however, greater when the phosphate was applied in one single dose than when applied in small increments during

TABLE 7. *The Effect of Varying Quantities of Phosphate and Limestone on the Yield of Red Fescue from Molinia Soil. Yield of Dry Matter from Each Cut (grams)*

Treatment per acre	*27.vi.34*	*7.viii.34*	*24.ix.34*	*10.xii.34*	*Total for 1934*	*3.v.35*	*10.vii.35*	*7.x.35*	*Total for 1935*	*Total for 1934–5*
A 1. 12 cwt. 8 per cent. basic slag	1·965	2·298	1·730	0·763	6·756	1·275	0·843	1·086	3·204	9·960
A 2. 12 cwt. 8 per cent. basic slag+ammonium nitrate	2·360	2·973	2·701	1·187	9·221	2·420	1·910	2·051	6·381	15·602
B 1. 12 cwt. 8 per cent. slag+30 cwt. limestone	3·725	2·515	1·983	1·323	9·545	2·206	1·391	1·669	5·266	14·811
B 2. 12 cwt. 8 per cent. slag+30 cwt. limestone+ammonium nitrate†	4·001	3·254	2·835	1·480	11·570	2·975	2·645	2·935	8·555	20·125
*C 1. 2 cwt. 8 per cent. slag+6 cwt. limestone	0·332	0·757	1·885	1·277	4·251	2·308	1·097	1·135	4·540	8·791
*C 2. 2 cwt. 8 per cent. slag+6 cwt. limestone+ammonium nitrate†	0·499	0·872	2·399	1·390	5·159	3·173	2·450	2·467	8·090	13·249
*D 1. 2 cwt. 8 per cent. slag+36 cwt. limestone	1·504	2·462	2·301	1·340	7·607	2·303	1·545	1·711	5·559	13·166
*D 2. 2 cwt. 8 per cent. slag+36 cwt. limestone+ammonium nitrate†	1·609	2·228	2·839	1·843	8·519	3·297	3·523	3·114	9·933	18·452

* All C and D plots also received the equivalent of 1·7 cwt. 8 per cent. slag after each cut (as monocalcic phosphate).
† 0·5 cwt. ammonium nitrate at time of sowing and after each cut.

the growing-seasons. The establishment of the grass is clearly more satisfactory when the phosphate is all supplied in the first dressing. In another series of pots where wild white clover was sown no establishment whatsoever was obtained with the low initial dressing of phosphate. It is evident, therefore, that on the *Molinia* soils the first manurial requirement is an adequate supply of phosphate, and that this phosphate is rendered more effective by the inclusion of limestone. These pot experiments also show the advantage to be gained from nitrogen as ammonium nitrate in increasing the efficiency of slag and limestone dressings on the *Molinia* soil. As it has been previously shown that a small amount of nitrogen improves the establishment of wild white clover [1], its inclusion in the manurial dressing is evidently desirable.

The Effect of Extreme Conditions of Management on the Yield of Dry Matter and Chemical Constituents from the Produce of Upland Areas

These experiments on the *Molinia* and fescue areas were carried out under conditions that entirely excluded the grazing animal. In the fairly lenient system of cutting adopted, three cuts were taken in each season during the first three seasons (1931–3) and four cuts during the subsequent two seasons. Thus the conditions were far removed from those which would have prevailed had the grazing animal been allowed access to the plots. Apart from a little limestone and ammonium nitrate applied to some of the plots in 1934, none of the manurial constituents was being returned to the soil, and the plots suffered considerably from lack of consolidation that would be afforded by sheep.

When these experiments on the fenced plots were begun, another series of experimental plots was started by Thomas on adjacent ground to study the introduction and maintenance of species and strains under actual open-hill grazing conditions [5]. These experimental plots were obtained on a cultivated strip nearly one mile long and two yards wide by dividing it into 1/100-acre plots. The cultivation consisted in tearing off the turf and harrowing the surface-soil; the seeding was made up of seedsmen's cleanings (chiefly Yorkshire fog, crested dogstail, perennial rye-grass, and wild white clover), and not the mixture of indigenous pedigree grasses and clover used in the enclosed area. In some of these open-hill plots, however, the manures used were similar to those adopted in several of the enclosed plots, and, as in the enclosed plots, wild white clover made an important contribution where the manurial treatment adopted had proved satisfactory for its development. It was considered, therefore, that useful data might be obtained by a quantitative comparison of some of the more radical changes effected in the open area intensively grazed by sheep with the changes brought about in the enclosed plots. For this purpose samples were taken during 1934–5 from a number of the open plots by means of cages, these samples being dried and analysed. The samples were taken with the same frequency as those from the enclosed plots, and enabled a comparison to be made between the relative yields obtained from the open-hill and the enclosed-hill areas during the two seasons. These results are summarized in Table 8.

TABLE 8. *Dry-matter Yields obtained from Pastures in Upland Areas: (A) Accessible to Sheep from Time of Sowing; (B) Not Grazed from Time of Sowing (1931). (Yields in gm. per 4 sq. yds.)*

		1934		*1935*		*Total for 1934–5*	
Treatment per acre	*Area*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
1 cwt. basic slag .	A. Open	52	255	105	318	157	573
Nil	B. No grazing	107	213	189	274	296	487
5 cwt. basic slag .	A. Open	456	449	360	532	816	981
12 cwt. ,, ,, .	B. No grazing	240	292	412	472	652	764
2 tons quicklime .	A. Open	35	434	278	715	313	1,149
12 cwt. basic slag+1 ton limestone .	B. No grazing	340	312	715	436	1,055	748

The above table shows that on the fescue soil a higher yield has always been obtained from the open area than from the enclosed plots. This is due mainly to the manuring and consolidation effected by the sheep; and this effect of the grazing animal is clearly brought out when the produce of the open fescue plots receiving 5 cwt. slag is compared with that of the enclosed fescue plots to which 12 cwt. slag had been applied. In spite of the heavier dressing of slag received by the enclosed area a higher yield was obtained from the grazed plots. A decidedly higher yield was also forthcoming from the grazed-fescue area heavily limed than from the enclosed area to which both slag and lime had been applied; but this statement does not apply to the *Molinia* area, from which the response to quicklime alone has been disappointing. The response of the grazed *Molinia* area to 5 cwt. basic slag has, however, been very pronounced. This confirms in the field the finding of the pot experiments previously described, namely, that the primary need of the *Molinia* soil is phosphate; and it also shows that its need for this constituent is greater than that of the fescue soil.

The yields from the grazed plots indicate that where a good dressing of basic slag has been applied, the attention of the sheep has been fairly uniformly divided between the fescue and *Molinia* areas. Where, however, the dressing of slag has been small, or where lime only has been applied, the superior yields forthcoming from the fescue plots under these conditions indicate that the sheep prefer them. The way in which the sheep have influenced the chemical composition of the sward is brought out in Table 9.

Table 9 shows that there is no significant difference between the nitrogen-content of the samples from the grazed and ungrazed plots in the *Molinia* area, but that in the fescue area there is a higher nitrogen concentration in the grazed herbage. These results, in conjunction with the dry-matter yields (Table 8), mean that the protein derived from the herbage of the fescue area is much higher under intensive grazing than under a system of periodic cuts, and reflect the nitrogen returned to the soil by the grazing animal. There is also a high protein yield from those *Molinia* plots which have received special attention from the sheep, namely, those to which a good dressing of basic slag had been given.

The above results show that the produce of the enclosed areas had a higher lime-content than that of the open plots, and that during 1934,

the first season when cages were put down for the purpose of this sampling, the produce of the grazed plots was superior in phosphate. As a consequence there is a change in the lime-phosphate ratio as we pass from the enclosed to the open areas, this ratio being lower in the

TABLE 9. *Percentage Chemical Composition of Pastures during Third and Fourth Harvest Years in Upland Areas: (A) Accessible to Sheep from Time of Sowing; (B) Not Grazed from Time of Sowing (1931)*

		1934				*1935*			
Treatment per acre	*Area*	*Nitrogen* (N)	*Calcium oxide* (CaO)	*Phosphoric acid* (P_2O_5)	*Ratio* CaO : P_2O_5	*Nitrogen* (N)	*Calcium oxide* (CaO)	*Phosphoric acid* (P_2O_5)	*Ratio* CaO : P_2O_5
1. Molinia *soil*									
1 cwt. basic slag	A. Open	1·75	0·415	0·284	1·46	1·97	0·438	0·349	1·26
Nil	B. No grazing	1·79	0·690	0·249	2·77	1·90	0·533	0·295	1·81
5 cwt. basic slag	A. Open	2·12	0·663	0·505	1·31	2·31	0·634	0·349	1·81
12 cwt. basic slag	B. No grazing	2·23	0·830	0·460	1·80	2·28	1·047	0·541	1·94
2 tons CaO	A. Open	2·42	0·747	0·542	1·37	2·28	0·764	0·363	2·11
12 cwt. slag + 1 ton $CaCO_3$	B. No grazing	2·54	0·940	0·440	2·14	2·19	1·153	0·510	2·26
2. Fescue soil									
1 cwt. basic slag	A. Open	1·98	0·473	0·360	1·31	1·83	0·473	0·394	1·20
Nil	B. No grazing	1·62	0·610	0·233	2·62	1·82	0·518	0·290	1·79
5 cwt. basic slag	A. Open	2·18	0·629	0·459	1·37	2·02	0·565	0·414	1·36
12 cwt. basic slag	B. No grazing	2·05	0·870	0·530	1·64	2·14	0·955	0·498	1·92
2 tons CaO	A. Open	2·67	0·986	0·503	1·96	2·23	0·723	0·394	1·84
12 cwt. slag + 1 ton $CaCO_3$	B. No grazing	2·21	0·920	0·440	2·09	1·57	0·991	0·487	2·04

produce of the grazed plots. The lime-phosphate ratio is exceptionally high in the produce of the enclosed area, and the herbage of the grazed area with its lower ratio probably approaches closer to the condition of a mineral balanced ration.

Botanical Composition of the Herbage on the Two Soils

As previously mentioned, the sown species of the enclosed plots were perennial rye-grass, cocksfoot, and wild white clover. An analysis of the herbage on a tiller basis was conducted in August 1934, and again in August 1936. The results show that in the sown plots the rye-grass decreased in the fescue area, but in the *Molinia* area the number of rye-grass tillers was greater in relation to the other species, and had increased in certain plots. The difference in the cocksfoot of the two areas was not so marked, but the *Molinia* plots were superior, the relative numbers having increased in almost all the sown plots. Wild white clover had increased throughout the whole experiment, and had, moreover, come into most of the unsown plots. Bent had decreased throughout the plots of both soils, but fescue had markedly increased. Where, however, complete manures had been applied, this diminution in bent was much smaller, and in 1936 the manured plots contained a higher proportion of bent and a lower proportion of fescue than the unmanured. Over the period under review the amount of moss had increased in the fescue plots, but had decreased in the *Molinia* plots.

The botanical composition in 1936 showed that in both areas the

sown species had been retained most successfully in those plots where limestone had been included with the basic slag.

The behaviour of the perennial rye-grass indicates that more fertile conditions prevailed in the *Molinia* area. This was especially marked where limestone had been included in the manurial dressing, thus supporting the inference from the chemical data, namely, that the limestone had a more lasting beneficial effect on this area. The marked difference in the relative amounts of moss shows the superior condition of the sward in the *Molinia* plots.

Further botanical data were obtained from a productivity analysis made on the herbage prior to each cut in 1935. The results show that perennial rye-grass contributed more to the 'keep' of the *Molinia* area than it did in the fescue area, as would be expected from the tiller analysis. The cocksfoot, however, contributed more to the produce of the fescue plots. The contribution of wild white clover to the yield of herbage on all plots was similar for the two areas. No clover whatsoever was obtained in those plots that had been seeded and cultivated but had received no manures. This failure of wild white clover to 'take' emphasizes the importance of manures for these hill soils. The behaviour of wild white clover in regard to the unsown plots of the two soils is particularly interesting: it made a volunteer appearance in some but not in all of the plots where no clover had been sown. This appearance invariably occurred on those plots which had received both basic slag and limestone, and invariably failed to occur on those plots to which neither of these manures had been applied. Where basic slag alone had been added, the invasion by clover was conditional on cultivation, no successful invasion taking place where cultivation had not been carried out. Where limestone had been jointly applied with the slag, the invasion was successful in the uncultivated areas as well as in the cultivated. This behaviour was the same for both soils and affords clear evidence of the added inducement afforded by limestone to a successful clover establishment.

Summary and Conclusions

A comparison is made of the response of *Molinia* and fescue soils from the Plynlymon area to different treatments over a period of five years (1931–5). These treatments consisted of both separate and combined cultivation, manuring, and the sowing of pedigree grasses and wild white clover. The outstanding feature of the results is a marked increase in yield, coupled with a much higher concentration of nutrients in the herbage of the treated plots from both the *Molinia* and fescue soils. A higher yield of natural herbage was obtained as a result of manuring and cultivation from the fescue soil than from the *Molinia* soil. This is attributed to the greater power to withstand cutting possessed by the vegetation of the fescue soil, and to the drier conditions that existed therein. As a result of periodical cutting, transformation from a *Molinia* to a fescue herbage occurred on the *Molinia* soil, which was greatly accelerated by manuring. Manuring also effected a marked increase in the bent-fescue ratio of the herbage.

The introduction of cultivated grasses and wild white clover brought about an increased yield of dry matter from both soils, compared with the yield from the treated natural herbage. It also changed the relative yielding capacity of these soils, so that in the presence of the sown species the productivity of the *Molinia* plots equalled, or even exceeded, that of the fescue. Where basic slag was used, either alone or in conjunction with a very small quantity of limestone, the yield from the *Molinia* soil equalled that from the fescue. Where limestone to the extent of 1 ton or over was added to the basic slag, the yields from the *Molinia* plots exceeded those from the fescue plots.

During the experiment wild white clover made a volunteer appearance in some but not all of the plots where no clover had been sown. This appearance invariably occurred on those plots which had received both basic slag and limestone, and invariably failed to occur on those plots to which neither of these manures had been applied. Where limestone had been jointly applied with the slag the invasion was successful in the uncultivated as well as in the cultivated areas, but this was not the case where slag alone had been used. The effectiveness of limestone was conspicuous in both soils, but it was found to produce a greater increase in the dry matter and chemical constituents of the herbage grown on the *Molinia* than on the fescue soil.

Perennial rye-grass made a greater contribution to the herbage of the *Molinia* than to that of the fescue soil, particularly where limestone had been included in the manures. Over the period under consideration the amount of moss had increased in the fescue plots, but had decreased in the *Molinia* plots. The results show evidence of greater leaching from the fescue than the *Molinia* area, and this largely accounts for the difference in response to limestone obtained from the two soils.

Limestone was found to have a marked influence on the recovery of phosphate from basic slag in the herbage. Comparing the *Molinia* soil to which high grade basic slag alone was applied with the same soil in which the slag dressing was supplemented with 1 ton limestone, the percentage recovery of phosphate over a period of five years in the first case amounted to 17·1 per cent. compared with 26·2 per cent. in the second. In the fescue soil practically as good a recovery was obtained from 10 cwt. limestone as from higher quantities, and where this quantity was applied, a recovery of 21·9 per cent. was obtained, compared with 16·2 per cent. where basic slag only had been used.

Pot experiments carried out on the *Molinia* soil point to the paramount need in this soil for a liberal initial dressing of phosphates. Very unsatisfactory establishment was obtained with a small dressing of basic slag, and the response from limestone together with a good dressing of basic slag was much greater than that from limestone in conjunction with a small quantity of slag. Field experiments are referred to where lime alone was found to have little influence on the *Molinia* soil, but a pronounced beneficial effect on the fescue soil.

The produce of enclosed and manured hill plots is compared with that of open strips on the hill country. These strips had been cultivated, manured, and seeded at the same time as the plots, but, unlike the latter,

they had been intensively grazed by sheep for the previous three years. The results show that manuring and consolidation by sheep effected a marked increase in yield of dry matter and chemical constituents. The herbage of the grazed strips had a lower lime-phosphate ratio than the exceptionally high ratio of the enclosed plots.

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THE EFFECTIVENESS OF CULTURAL TREATMENTS IN THE CONTROL OF WEEDS

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FROM the earliest days of farming the necessity for weed eradication has been recognized, and various methods, both chemical and cultural, have been sought for their control. Apart from the herbicides that are now in use, the potentialities of cultural treatments like improved methods of tillage, manuring, and suitable rotations, have all to be considered. The various species of weeds differ so much in their characteristics and adaptability to the climate and soil conditions obtaining in these tropical regions, and they vary so greatly in their effects on different crops according to different cultural treatments, that it is impossible to formulate any general method of treatment.

Warington [1], Brenchley and Warington [2, 3] have thrown light on the association of certain weed-flora and manuring in a field with a history of uniform crop-production. In her earlier works of similar nature, Brenchley [4, 5, 6, 7] made a detailed qualitative study of the association of weed-flora with certain soils. A quantitative study of the various cultural treatments, such as variety of crop, seed-rate, manuring, and rotation, as a means of control has not yet been attempted. Still less has the classical method of Fisher's analysis of variance [8] been applied to problems of weed-control in which a number of biological factors operate to produce a joint result. In a recent publication Lynes [9] has applied this method in a study of the eradication of *Convolvulus arvensis* by chemicals. Apart from the admitted shortcomings of the experimental technique, the single weed-count he made on a single date does not seem to give a correct estimation of the stand of the weed.

The present paper deals with the first part of a programme of weed-control undertaken at this Station. The experiments herein discussed were designed to study the control of weeds by cultural treatments, and extend over a period of four years, but the actual results are deduced from the mean of the last three years. Altogether 22 treatments were used (Table 2); each treatment was replicated 6 times in plots of 108 sq. ft. arranged in 6 blocks of equal area; and each block consisted of 22 plots. The 22 treatments were allotted at random to the plots within each block, as developed by Fisher, 'to ensure that the differences utilized in the estimation of error (by which the differences between unlike plots are judged) are properly representative of the other errors which produced the actual errors of the experiments'. The treatments are given in Table 2.

Chenopodium album L., which was found to be the most frequent and most dominant weed in a previous quantitative study of the weed-flora on arable lands, is taken as a test of the effectiveness of the treatments represented in Table 2. From the beginning of the experiment in September, 1932, until the weed-counts were made in 1933, 1934, and 1935,

TABLE 3. *Mean Squares, Percentage Weed-stands*

	D.F.	*Early minimum*	*Maximum density*	*Late minimum*
Blocks	5	1,286·014	1,556·185	456·96
Treatments	21	*13,165·110	*8,287·660	*6,364·24
Error	105	507·541	598·350	2,100·10
	131			

* Significant at 1 per cent.

TABLE 4. *Average Percentage Weed-stand for the Various Treatments at the Early Minimum Stage*

	Fallow		*Wheat*			*Linseed*			*Gram*			
	Unploughed	*Ploughed*	*75 lb.*	*100 lb.* (N)	*125 lb.*	*8 lb.*	*10 lb.* (N)	*12 lb.*	*80 lb.*	*90 lb.* (N)	*100 lb.*	*Mean*
Unmanured	91·7	100·6	127·5	104·8	30·9	70·2	56·4	42·9	45·9	24·2	12·8	64·35
Manured	145·8	156·7	181·1	136·7	52·6	116·8	107·9	75·6	78·9	39·4	25·7	101·35
Mean	118·75	128·65	154·3	120·75	41·75	93·5	82·15	59·25	62·4	31·8	19·25	82·9

Standard error of the mean of treatments 9·19.
Critical difference required for significance 27·57.

TABLE 5. *Average Percentage of Weed-stand for the Various Treatments at the Maximum Density*

	Fallow		*Wheat*			*Linseed*			*Gram*			
	Unploughed	*Ploughed*	*75 lb.*	*100 lb.* (N)	*125 lb.*	*8 lb.*	*10 lb.* (N)	*12 lb.*	*80 lb.*	*90 lb.* (N)	*100 lb.*	*Mean*
Unmanured	104·0	96·4	108·7	91·5	62·2	120·3	73·6	51·1	60·2	82·9	29·6	80·04
Manured	121·9	143·0	143·5	140·0	84·9	123·0	92·5	87·2	128·4	85·9	65·4	100·4
Mean	112·9	119·7	126·1	115·7	73·5	121·6	83·0	69·1	94·3	84·4	47·5	90·22

Standard error of the mean of treatments 9·99.
Critical difference required for significance 29·97.

TABLE 6. *Average Percentage Weed-stand for the Various Treatments at the Late Minimum Stage*

	Fallow		*Wheat*			*Linseed*			*Gram*			
	Unploughed	*Ploughed*	*75 lb.*	*100 lb.* (N)	*125 lb.*	*8 lb.*	*10 lb.* (N)	*12 lb.*	*80 lb.*	*90 lb.* (N)	*100 lb.*	*Mean*
Unmanured	99·4	101·9	155·0	135·7	55·6	125·9	80·8	49·8	72·8	46·1	46·8	88·1
Manured	159·6	189·8	175·4	157·4	85·15	154·3	100·1	67·5	122·4	61·0	75·3	122·5
Mean	129·4	145·8	165·2	146·6	70·3	140·1	90·4	58·5	97·6	53·5	61·0	105·3

Standard error of the mean of treatments 18·71.
Critical difference required for significance 56·13.

2. Increase in the seed-rate of the crop results in a significant decrease of the weed-density, maintaining the same level of significance during the three stages.
3. The application of farm-yard manure has significantly increased the weed-infestation over that of the corresponding non-manured plots, owing to further infestation of viable weed-seeds.
4. Among the crops taken for experimentation the leguminous crop brings about a relatively high reduction in weed-density, maintaining more or less the same level of significance in all the three stages.

Summary

On the whole, the observations indicate that increased seed-rate has a definite effect on weed-control in fields infested with *Chenopodium album* L., and that farm-yard manure increases the weed-density. The data here presented throw light on the further possibility of weed-control by cultural treatments.

A record of the counts of each individual plot at each of the dates given in Table 1 has been filed in the archives for biological measurement established at the Natural History Museum at South Kensington.

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CRIMP OF MERINO WOOL A PERIODIC FUNCTION OF TIME?

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Introduction.—As a result of an extensive study of locks of wool obtained from various sources, Norris and van Rensburg [1], Norris and Claassens [2], and Norris [3], have concluded that crimp in wool is a periodic function of time. Norris and van Rensburg state that 'the total number of crimps per fibre in the fibres of any lock is constant and independent of the length of fibre'. Unfortunately the authors are not quite clear as to what they mean by the term 'lock'. Where the authors discuss their experimental method they state: 'It was most satisfactory to take the chosen fibres from the lock as a small bunch, that is so that the fibres measured had all been grown in close proximity to one another.' If by the term 'lock' is meant a staple, a sub-staple, or even a strand, one can scarcely imagine that the small bunch of fibres which were selected and grew in close proximity to one another could have been representative of the lock. The interesting results obtained therefore only show that the number of crimps per fibre, irrespective of the length of fibre, is the same for a bunch of fibres growing in close proximity. Most of these bunches consisted of only 68 to 120 fibres, but one consisted of 193 fibres and another of 347 fibres. Fibres from different bunches of the same lock may not show the same number of crimps irrespective of fibre-length.

This study was started to discover whether the phenomenon of crimp as a periodic function of time also holds good when a number of fibres is selected from a small sample (2×2 cm.).

Material used.—Four wool-samples were selected, three of which were taken from the shoulder region and one from the britch of different sheep. The wool was of a ten-months' growth and shorn from wethers of about three years of age. Each of the samples taken covered an area 2×2 cm. of body-surface. Several strands were selected from each sample and analysed for fibre-length and crimps.

Method.—The fibre-length was obtained by holding each end of a fibre by a pair of forceps, stretching the fibre along a millimetre ruler until the crimps were very nearly straightened out, and reading off the straight fibre-length from the ruler. One mm. was added to the length of each fibre to allow for the portion held in the jaws of the forceps. As the fibres were measured they were graded into length-classes, the range of each class being 5 mm.

After measuring a reasonable number of fibres from a sample, all the fibres of a length-class were laid out on a black plush cloth, gently pressed down, and the crimps of each fibre counted by the aid of a binocular with $\times 25$ enlargement. The number of crimps per fibre of each length-class was then averaged. The results are given in Table 1.

TABLE 1. *Relation between Fibre-length and Number of Crimps in the Same Sample*

Sample no.	*Length-classes mm.*	*Number of fibres per class*	*Av. number of crimps per class*	*Number of crimps per 10 cm. straight length*
5 (Britch) .	41–45	2	20·5	48·2
	46–50	9	23·1	48·7
	51–5	12	25·4	48·4
	56–60	13	29·0	50·4
	61–5	25	30·1	48·1
	66–70	30	31·8	47·1
	71–5	41	33·7	46·4
	76–80	82	35·0	45·1
	81–5	68	36·8	44·6
	86–90	78	38·3	43·8
	91–5	46	39·7	42·9
	96–100	19	39·8	41·8
	101–5	8	41·5	40·6
6 (Shoulder) .	51–5	2	27·0	51·4
	56–60	5	33·6	58·4
	61–5	2	38·0	60·8
	66–70	..	..	..
	71–5	7	40·3	55·6
	76–80	6	44·8	57·9
	81–5	17	46·8	56·7
	86–90	35	47·8	54·6
	91–5	60	49·3	53·3
	96–100	63	50·5	51·8
	101–5	41	51·9	50·6
	106–10	16	53·7	50·0
	111–15	4	54·5	53·1
7 (Shoulder) .	46–50	18	23·0	48·4
	51–5	20	25·3	48·2
	56–60	20	27·4	47·4
	61–5	64	30·0	46·4
	66–70	70	31·9	47·2
	71–5	56	34·0	46·8
	76–80	54	35·1	45·3
	81–5	61	36·3	44·0
	86–90	78	37·7	43·1
	91–5	59	38·8	41·9
	96–100	40	39·6	40·6
	101–5	18	41·8	40·7
	106–10	7	40·9	38·0
	111–15	3	43·3	38·5
	116–20	2	42·0	35·7
	121–5	1	47·0	39·1
9 (Shoulder) .	71–5	4	43·8	60·4
	76–80	15	48·0	61·0
	81–5	38	49·6	60·1
	86–90	65	51·4	59·8
	91–5	78	52·6	57·9
	96–100	78	53·9	55·3
	101–5	52	54·8	53·4
	106–10	34	56·2	52·3
	111–15	19	57·8	51·3
	116–20	6	58·8	50·8
	121–5	5	61·0	49·7

Discussion.—It is quite clear from Table 1 that for each sample there is a considerable variation in fibre-length and number of crimps per fibre. When leaving out of consideration those classes which contain less than five fibres we find differences between classes as large as those given in Table 2.

TABLE 2. *Difference in Fibre-length and Number of Crimps*

Sample no.	*Diff. in length between longest and shortest classes (cm.)*	*Diff. in av. number of crimps per fibre between longest and shortest classes*
5 (Britch) . .	5·5	18·4
6 (Shoulder) . .	4·0	13·4
7 (Shoulder) . .	6·1	17·9
9 (Shoulder) . .	4·5	13·0

Table 1 also shows that in each sample analysed there is an obvious increase in the number of crimps per fibre as the fibre-length increases. In Table 3 this is brought out clearly by the correlation coefficients found between average fibre-length and the average number of crimps per fibre of each class.

TABLE 3. *Correlation Coefficients between the Number of Crimps and the Length of Fibres composing a Sample*

Sample no.	*Number of fibres*	*Number of length-classes*	*Correlation coefficient*	*Regression value*
5 (Britch) . .	433	13	$+0·962 \pm 0·040$	1·567
6 (Shoulder) .	258	13	$+0·881 \pm 0·065$	2·095
7 (Shoulder) .	571	16	$+0·945 \pm 0·027$	1·315
9 (Shoulder) .	394	11	$+0·893 \pm 0·611$	1·364
Average			$+0·921 \pm 0·048$	

The high correlation coefficient of approximately 0·9 shows that a very close relation exists between the fibre-length and the number of crimps per fibre. From these results it appears that the phenomenon of crimp as a periodic function of time does not exist for fibres composing a small sample (2×2 cm.). In the area covered by such a sample the formation of crimp appears to be definitely related to length-growth. For the few samples analysed the regression values show that the crimps may increase by 1·3 to 2·1 for each 5 mm. increase in length of fibre.

It has been shown that in a staple there is a very high positive correlation between diameter and length of fibre [1, 4, 5]. As a high positive correlation is also found between fibre-length and number of crimps per fibre in the same sample, one may also assume a high positive correlation between fibre-diameter and number of crimps per fibre. The coarser a fibre of a small sample, the greater should be its number of crimps.

In Figs. 1–4 the relation between length of fibre and number of crimps per fibre is represented graphically. These graphs clearly show the increase in number of crimps with increasing length of fibre.

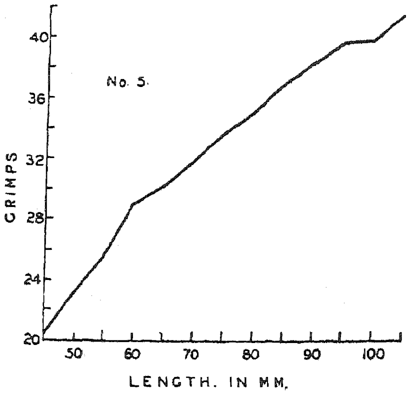

FIG. 1

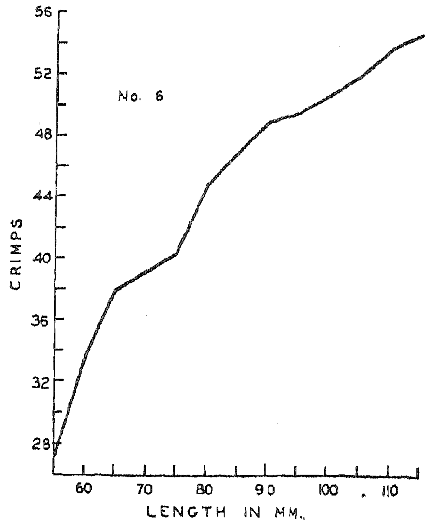

FIG. 2

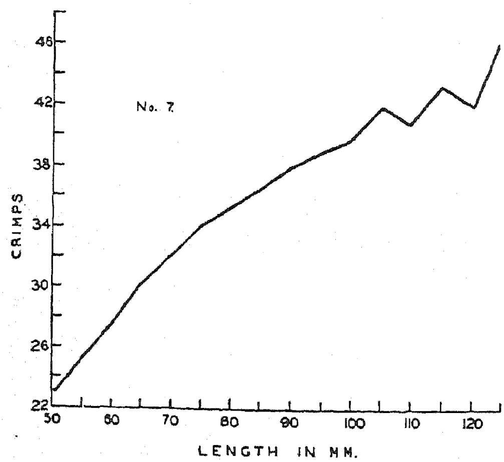

FIG. 3

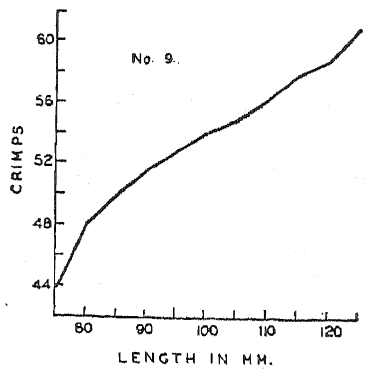

FIG. 4

FIGS. 1 to 4. Relation between fibre-length and number of crimps.

A criticism against the graphs of Norris and co-workers [1, 2, 3], is that 1 cm. length of fibre represented in the abscissa is made to correspond with 10 crimps as represented in the ordinate, whereas in the case of the merino samples analysed their tables show that in 1 cm. length of fibre there is approximately only 4 crimps, and with the crossbred wools 1 cm. length of fibre has approximately only 2 to 3 crimps. If the abscissae and ordinates of their graphs were adjusted proportionately, the line representing the relation between fibre-length and number of crimps would, in several cases, have shown a much steeper grade where the

number of crimps showed some increase with the increase in length. From the last column of Table 1 it will be noticed that an increase in fibre-length corresponds with a decrease in the number of crimps per unit straight length. This is clearly illustrated by the graphs in Fig. 5, which were constructed from Table 1 with elimination of those classes containing 5 fibres or less. For the number of crimps per given straight length to decrease, the crimps must be either further apart or they must be deeper, or both. When a number of fibres from a sample are laid out on a black plush cloth without stretching the fibres, it will be noticed that the long fibres are more deeply crimped than the short ones, and that they have fewer crimps per unit crimped length. Apparently, therefore, both factors are at work and we find that the longer the fibres the further apart and the deeper are the crimps.

If we take No. 9 as an example, we find that according to Table 1 there are approximately 5·5 crimps to the centimetre straight length, the range being approximately 5 to 6. If the spacing between the crimps and the depth of the crimps remained constant with increase in fibre-length, the difference between each class should have ranged from 2·5 to 3·0 crimps with an average of 2·75. According to the regression value the difference between the classes is only 1·4 crimps. This clearly shows that the increase in number of crimps per fibre is not in absolute proportion to the increase in length. Probably this must be ascribed to a relative increase in depth and spacing of crimps with an increase in fibre-length. It therefore appears that although crimp in a sample of wool (2×2 cm.) is not a periodic function of time, the production of crimp is not in absolute proportion to the increase in length.

The question now arises whether, in samples covering a smaller surface area than 4 sq. cm., one will still find the number of crimps to increase as the fibres become longer. In a study of the properties of wool strands in a fleece [6], numerous strands (123) were analysed for length and crimp. The number of fibres composing a strand varied from 21 to 210, from which it is clear that strands of varying sizes were studied. In each case a wide distribution in number of crimps and length of fibres were found. In Table 4 some typical examples are given.

TABLE 4. *Distribution of Length and Crimp in Wool Strands*

Sample no.	*Range in crimps*	*Coefficient of variability*	*Range in length mm.*
2 (Belly) . .	26–36	8·5	61–95
	27–39	7·9	63–115
	26–35	9·2	64–101
	26–44	14·4	60–115
	24–32	8·6	60–97
	24–38	12·1	60–104
	25–33	10·9	62–100
	26–38	8·6	63–91

If crimp is a periodic function of time there should be very little variation in the number of crimps of the different fibres composing a strand, even if they vary considerably in length. As the number of

crimps per fibre show, however, great variation even in small strands composed of 21 to 46 fibres, the crimp cannot be considered a periodic function of time. As a result of this study we cannot, therefore, agree with the finding of Norris and co-workers that in the case of merino wool 'the total number of crimps in the fibres of any lock is constant and independent of the length of the fibre'.

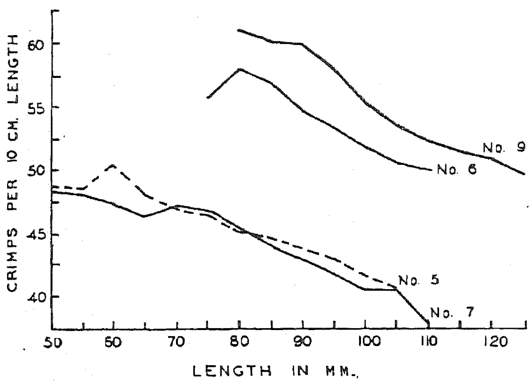

FIG. 5. Relation between fibre-length and number of crimps per unit length.

Conclusion.—From a study of the length and crimp of approximately 1,656 wool fibres taken from four samples of merino wool, each sample taken from 4 sq. cm. of body-surface, the following conclusions were drawn:

1. There is a considerable variation in the number of crimps and length of the fibres composing a sample.

2. A close relationship exists between the number of crimps and the length of the fibres composing a sample. A correlation coefficient of approximately $+0{\cdot}9$ was found and a regression value ranging from $1{\cdot}3$ to $2{\cdot}1$ crimps for each 5 mm. increase in length of fibre.

3. As a high positive correlation exists between diameter and length of fibre, one may also assume a high positive correlation between number of crimps and diameter of the fibres composing a sample.

4. As the fibre-length increases, the number of crimps per given straight fibre-length decreases. This is ascribed to an increase in depth and spacing of crimp as the fibre-length increases.

5. The authors do not agree with the finding of Norris and co-workers that in merino wool 'the total number of crimps in the fibres of any lock is constant and independent of the length of the fibre'.

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AGAVE FIBRES

Pt. I. MORPHOLOGY, HISTOLOGY, LENGTH AND FINENESS; GRADING PROBLEMS

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WITH PLATES 2, 3, 4

1. *Introduction*

When this station began to take an interest in Agaves as fibre-producing plants some years ago it soon became apparent that extremely little was known about the fibre itself, or, for that matter, about the plant. Shortly afterwards the work here reported was started. The original intention was to devise tests for facilitating the selection of fibre-producing plants in order that new plants could be selected for desirability of fibre as well as for vegetative characteristics. It is clearly impracticable to multiply all promising single-plant selections to the stage when a sufficiency of fibre can be sent to Europe for a spinning test. The area necessary for the plantations would be great; the time involved considerable; the expense prohibitive; and the ability of the spinning trade to evaluate a new fibre-type is problematical.

As time went on the work developed into a study of all readily measurable fibre-qualities; and in addition a number of correlations of plant-characters and fibre-qualities, suggested by increasing acquaintance with practical problems, has been undertaken. This expansion has been justified by the number of queries recently received from sisal producers, some of which we have been able to answer as a result of the information accumulating here; and it has therefore been thought advisable to publish the admittedly incomplete results so far available on the fibres of sisal and of related Agaves. Fuller treatment of some of the subjects of this paper will be made later.

2. *Morphology and Histology of Agave Fibres*

The Fibre in the Leaf

The fibre-distribution in the leaves of Agaves has been studied by means of sections. Preserved or embedded material is almost impossible to cut owing to the extreme hardness of the fibres when embedded and to the softness of the parenchyma surrounding them. Fresh material can, however, be sectionized with comparative ease, providing that the angle of the microtome knife is precisely adjusted. The knife is set to give a long, drawing stroke, and the surface of the fresh material is flooded with alcohol for not longer than one or two seconds before the section is made. Complete transverse sections up to 3 or 4 in. long can be obtained of 50 μ in thickness.

Staining has been by safranin, light green sometimes being used as a counter-stain. It is essential that the safranin be extremely dilute, and the best differentiation is obtained by staining for 48 hours in water just tinged pink by the stain.

Plate 2 shows the appearance of cross-sections of the leaves of *Agave sisalana*, *A. amaniensis*, and *A. cantala*. The distribution of fibres in all these can readily be seen as variations on a single theme. In all Agaves with which I am acquainted three main zones of fibres can be delimited:

1. A peripheral zone, composed of one or more rather irregular rows of small fibres. These are of nearly circular cross-section.
2. A median line of large fibres. These are horseshoe-shaped in cross-section, containing a conducting strand in the open side of the crescent, and a smaller fibre opposite to the xylem of the strand.
3. Fibres in the ground-tissue of the leaf. These form a series between the fibre-types of zones 1 and 2.

The chief variation between the species lies in the total number of fibres per leaf, and in the partition of them into their different types. This point will be dealt with later in more detail, but it is perhaps worth while pointing out, in passing, that one of the chief superiorities of *A. amaniensis* is the very large number of fibres per leaf.

Agave fibres fall into three types, all fairly clearly defined, although there does exist a series of transition forms connecting types 1 and 2.

1. *'Mechanical' fibres.*—These are most strongly developed round the periphery of the leaf, although they also occur scattered through the leaf parenchyma. They are small, rarely circular in cross-section, and usually of a more or less thickened horseshoe shape. They are rarely associated with conducting tissues. They vary in length from a few centimetres to almost the entire length of the leaf. These fibres are of great importance commercially, as, owing to their shape, they seldom divide during the processes of manufacture. The 'fineness' of a fibre-sample therefore depends, from a commercial viewpoint, almost entirely on the fineness of these fibres.

Figs. 1, 2, 3, 4, 5, and 6 illustrate bundles of this type from *A. americana*, *A. angustifolia*, *A. cantala*, *A. amaniensis*, *A. fourcroydes*, and *A. sisalana*. It will be seen that certain characters of the fibres are at once explicable on the basis of the microscopic structure. *A. fourcroydes* (Henequen), *A. americana*, and *A. angustifolia* are all characterized by large fibre cells, with comparatively wide lumina. These fibres are well known to be weaker than sisal, the latter having smaller cells with narrower lumina. *A. cantala* and *A. amaniensis* (Blue Sisal) on the other hand have very narrow lumina to the cells, resulting in a greater amount of fibre-substance per unit cross-section. Both fibres are markedly superior to sisal in strength, as will be apparent later. The shape of the peripheral bundles of *A. cantala* is very characteristic. Here the horse-shoe shape is nearly lost, and a very dense, cylindrical fibre results. These are exceptionally strong and supple and probably account for much of the popularity enjoyed by this fibre.

In addition to the peripheral mechanical fibres, there occur bundles of the same type scattered throughout the parenchyma of the leaf; these are indistinguishable in section from the peripheral fibres, and are probably also indistinguishable technologically.

2. *'Ribbon' fibres.*—These invariably occur in association with the conducting tissues. They are most strongly developed in the median

line of fibres previously referred to, though 'ribbon' fibres of various sizes are present in all parts of the leaf, excluding the extreme periphery. Each fibre is seen in section as a wide crescent, with the phloem of a vascular bundle in the open side. It is of normal fibre-structure, and of considerable mechanical strength. It forms part of the fibre of com-

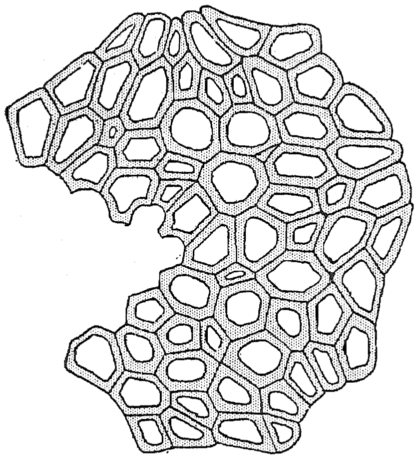


FIG. 1. *A. americana*

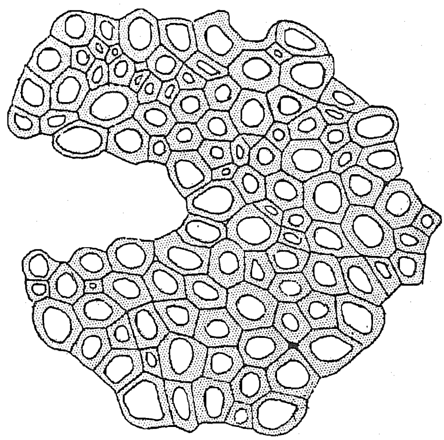


FIG. 2. *A. angustifolia*

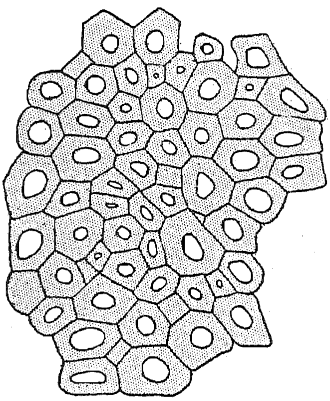


FIG. 3. *A. cantala*

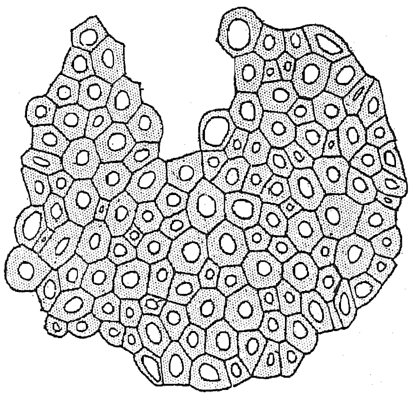


FIG. 4. *A. amaniensis*

merce, and is noteworthy as being the longest fibre in the leaf. These fibres run from base to tip, and if the fibres of a leaf are classified on the basis of length, the longest classes are entirely composed of these fibres. They are also important in that they readily split longitudinally, and in this way form a contrast to the mechanical fibres. The fineness of commercial fibre, therefore, is not dependent upon the original size of these fibres.

3. *'Xylem' fibres*. These fibres form part of the composite bundles of the median line of fibres. They occur opposite to the xylem of the vascular strand, and are of an irregular crescent shape. They are com-

posed of thin-walled cells, and are invariably broken up and lost during the process of decortication of the leaf. They are therefore of no commercial importance.

Plate 3 illustrates the component parts of a bundle from the median line of fibres of *A. sisalana*. The strong large fibre of the 'ribbon' type forms a marked contrast to the weaker xylem fibre.

Plate 4 illustrates the different types of bundles occurring in *A. sisalana* and *A. amaniensis*. Both sections include the extreme periphery of the leaf. The variation in fibre-size is well shown.

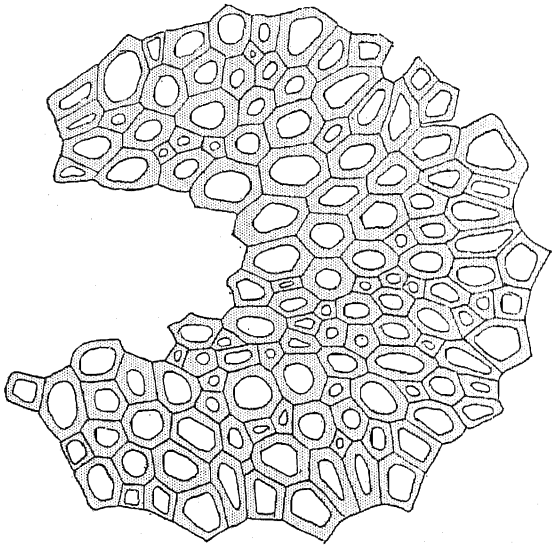


FIG. 5. *A. fourcroydes*

It will be seen that on the basis of fibre-characters, as revealed by a study of the section of the leaf, certain aids to plant selection can be enunciated. It is of advantage, in a selection, to have:

(*a*) Dense fibres, with narrow lumina to the fibre-cells. The mechanical strength of the fibres will thus be good.

(*b*) A large number of fibres per leaf. This will probably mean that the fibres will be fine, or that the percentage of fibre in the leaf will be high.

(*c*) Small mechanical fibres, of cross-section approximating to a circle.

3. *Length and Fineness of Fibre*

Relation between fibre-size and leaf-length.—Leaves were collected from plants of *A. sisalana*, *A. amaniensis*, *A. angustifolia*, and *A. cantala* and were so chosen that a wide range of lengths was obtained for each species. Basal sections were cut and stained in the usual manner, and all the peripheral fibres of each leaf drawn under a camera lucida at a magnification of 100 diameters. These drawings were then measured with a planimeter. By this means the average cross-sectional area of the bundles could be obtained with a considerable degree of accuracy.

The peripheral bundles were chosen because the 'ribbon' fibres, as previously explained, invariably divide longitudinally during the processes involved in the manufacture of cordage, and hence the fineness of the sample is not affected, commercially, by the size of these. In addition, the greater number of the peripheral bundles makes them the most important factor in determining the fineness of a sample.

The results are illustrated in Fig. 7. The regression for all species is linear, and all the lines are parallel. This is of especial interest in that some of the plants were grown at Amani, at an altitude of 3,000 ft. and with a rainfall of about 80 in., whilst others were collected from the coastal plain at an altitude of only a few feet above sea-level, and with a rainfall of about 40 in. The influence of the district wherein the fibre was grown is seen to be but slight.

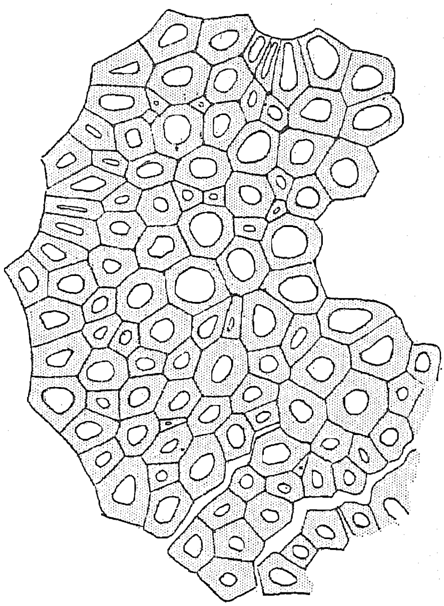


FIG. 6. *A. sisalana*

These figures are of some practical interest. In view of the uncertainty as to the real requirements of the spinners, certain planters have followed the practice of cutting their plants while the leaves were still short, or of deliberately planting sisal on areas where the conditions give rise to a short leaf, with the intention of producing a fine fibre, at the sacrifice of length. The graph shows that such a practice will have but little of the desired effect.

The average length of leaf produced on a well-managed commercial estate rarely exceeds 105 cm., as will be shown in detail later. This will produce fibres of average cross-sectional area of $2{\cdot}9 \times 10^{-2}$ sq. mm. Assuming that an endeavour is being made to produce short leaf, it is improbable that the length would average less than 80 cm. or the fibre would be condemned on the ground of shortness. This length will produce fibre of area $2{\cdot}6 \times 10^{-2}$ sq. mm.: a reduction of 10 per cent. by area or a decrease in diameter of only 5 per cent. Precise measurements would be necessary to recognize such a slight increase in fineness, whilst the shortness of the fibre would probably result in unfavourable comment.

If fineness is to be regarded as a desideratum, it can more readily be obtained by the use of other Agave species which will produce fibres of greater fineness with no concomitant reduction in leaf-length. *A. cantala* and *A. amaniensis* will, under all conditions, produce fibres which are markedly finer than are those of *A. sisalana*.

Relation between fibre-length and fineness.—Leaves of *A. sisalana* and *A. amaniensis* were decorticated by gently beating the leaf under a stream

of water. In this manner the complete range of fibres was obtained, none being lost or split during decortication. Each individual fibre was measured, and the total amount of fibre from each species was sorted into 10 cm. length-classes. Each class was counted and weighed. Fig. 8 illustrates the results, where fineness, as measured by the weight per unit length, is plotted against the length of the fibre. The difference between the two species is diminished by this method of plotting. Weight per unit length will only give a true comparison of dimensional

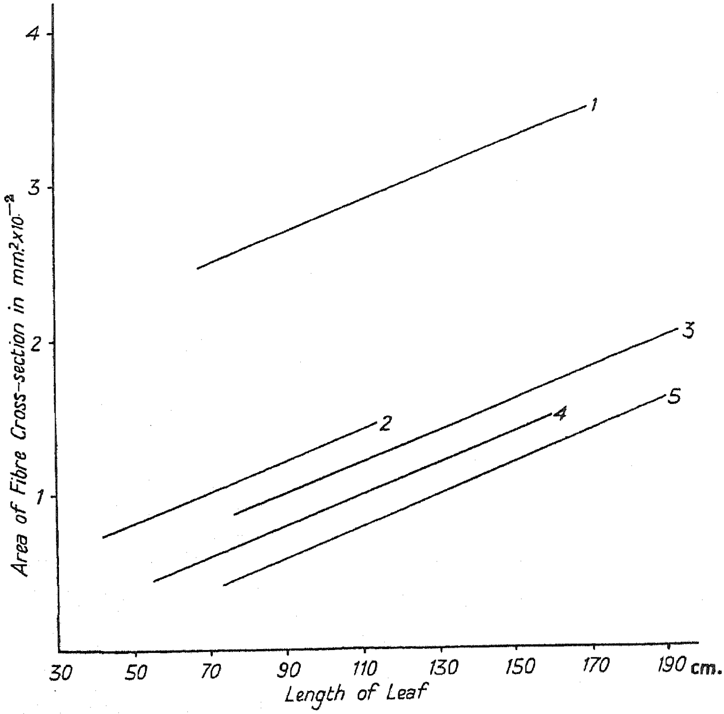


FIG. 7. Relation between leaf-length and fibre-size in Agaves. 1. *A. sisalana* grown in hills. 2. *A. angustifolia* grown in hills. 3. *A. amaniensis* grown in hills. 4. *A. cantala* grown on plains. 5. *A. amaniensis* grown on plains.

fineness when the densities of the two species under comparison are the same. We have seen that the fibres of *A. amaniensis* are apparently denser than those of *sisalana*. This has been confirmed by actual measurements. The difference in fineness, therefore, if converted to a basis of diameter, would be greater than is apparent on the graph.

It is to be noted that the regressions of fibre-length on fineness are linear and parallel, the fibres of blue sisal being finer than those of sisal for all values of fibre-length commercially practicable.

An important point is that the *difference* in fineness of the two species is constant. That is, the ratio of comparative fineness decreases with increasing leaf-length. A 20-cm. fibre of blue sisal is approximately twice as fine as a fibre of sisal of that length, whereas a 100-cm. fibre is only about $1\frac{1}{2}$ times as fine. This is not of such commercial importance as might

be supposed, since the long fibres are almost entirely of the ribbon type, which splits longitudinally during manufacture, and hence does not affect appreciably the fineness of the commercial product. It is otherwise with the fibres of medium length: they do not split at all, or but rarely, and their fineness determines the commercial fineness of the whole.

The separation of the fibres of agaves into their fibre-types by any process of length-grading on the basis of *fibre*-length has a distinct bearing on grading practice. This point will be dealt with later.

Distribution of fibre by length in agave leaves.—A series of leaves of sisal and of blue sisal was obtained covering a wide range of leaf-lengths for each species. Each leaf was decorticated separately by beating under a stream of water. The fibres were classified according to length, and weighed. For comparison a series of sisal leaves was decorticated on

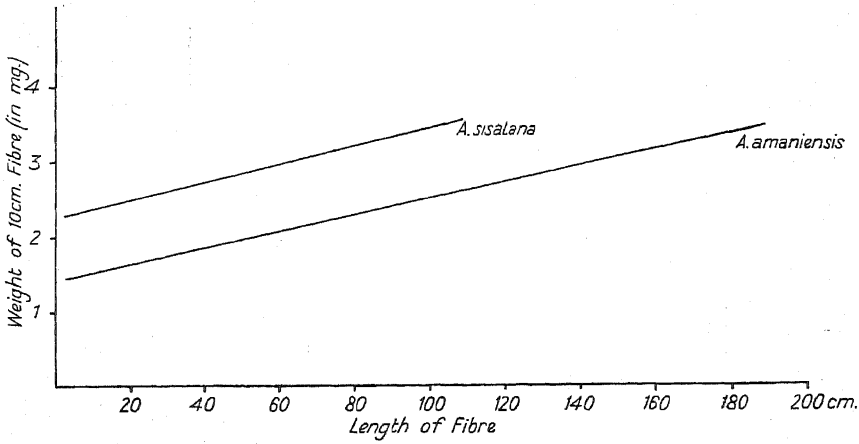


FIG. 8. Relations between length and fineness of fibre for *A. sisalana* and *A. amaniensis*.

a raspador. The waste amounted to 19 per cent. of the total fibre, and as this proportion of waste approximates to that normally obtained on commercial decorticators it may be assumed that the severity of decortication was similar to that prevailing on estates.

The following tables present the results for hand decortication:

In Table 1 the figures represent the weights of sisal fibre, for a series of leaf-lengths, as given at the head of each column, expressed as percentages of the total weight of fibre in each leaf, falling within the length-classes to the left of the table. Table 2 gives comparative figures for blue sisal.

In Fig. 9 the results of the three distributions are plotted; and since the important point in practice is the percentage of fibre below any standard length, the results are given in that form. All figures are reduced to a standard leaf-length. From these curves can be read off at once the percentage by weight of fibre falling below any given length for any leaf-length. All that is necessary is to express the fibre-length, taken as standard, as a percentage of the leaf-length and the results are at once available.

TABLE 1. *Distribution of Fibres by Length in Sisal Leaves*

Length of fibre	*Length of leaf in cm.*											
	50	*60*	*70*	*80*	*90*	*100*	*110*	*120*	*130*	*140*	*150*	*160*
cm.												
0–10	1	1	1									
10–20	7	4	3	2	1	1	1					
20–30	16	10	7	5	4	3	2	2	1	1	1	
30–40	27	17	11	8	6	5	3	3	3	2	2	1
40–50	49	25	16	12	9	7	5	4	3	3	2	2
50–60	..	43	25	15	11	9	8	6	5	4	3	3
60–70	..	..	37	25	16	11	9	7	6	5	5	4
70–80	..	..	..	33	23	15	11	10	8	6	5	5
80–90	..	..	..	..	30	22	15	11	9	8	7	6
90–100	..	..	..	..	..	27	22	15	10	9	7	6
100–110	..	..	..	..	..	..	24	20	15	11	8	7
110–120	..	..	..	..	..	..	..	22	19	15	11	8
120–130	..	..	..	..	..	..	..	..	21	17	15	11
130–140	..	..	..	..	..	..	..	..	..	19	16	13
140–150	..	..	..	..	..	..	..	..	..	..	18	17
150–160	..	..	..	..	..	..	..	..	..	..	..	17

TABLE 2. *Distribution of Fibres by Length in Blue Sisal Leaves*

Length of fibre	*Length of leaf in cm.*													
	70	*80*	*90*	*100*	*110*	*120*	*130*	*140*	*150*	*160*	*170*	*180*	*190*	*200*
cm.														
0–10	5	4	3	3	3	2	2	2	2	1	1	1	1	1
10–20	8	7	7	5	5	4	4	3	3	3	2	2	2	2
20–30	11	9	8	7	6	5	5	4	4	4	3	3	3	3
30–40	14	10	8	7	6	6	5	5	4	4	4	3	3	3
40–50	15	13	10	8	7	6	6	5	5	4	4	3	3	3
50–60	18	14	12	9	8	7	6	6	5	4	4	4	4	3
60–70	29	16	12	11	9	8	7	6	5	5	4	4	4	4
70–80	..	27	15	12	10	9	7	7	6	5	5	5	4	4
80–90	..	..	25	13	11	10	8	7	6	6	5	5	4	4
90–100	..	..	..	24	13	10	9	8	7	6	6	5	5	4
100–110	..	..	..	..	22	13	10	8	7	7	6	6	5	4
110–120	..	..	..	..	..	20	12	10	9	7	7	6	5	5
120–130	..	..	..	..	..	..	19	11	9	8	7	6	6	5
130–140	..	..	..	..	..	..	..	18	11	9	8	7	6	5
140–150	..	..	..	..	..	..	..	..	17	11	8	7	6	6
150–160	..	..	..	..	..	..	..	..	..	16	10	8	7	6
160–170	..	..	..	..	..	..	..	..	..	..	16	10	8	7
170–180	..	..	..	..	..	..	..	..	..	..	..	15	10	7
180–190	..	..	..	..	..	..	..	..	..	..	..	..	14	10
190–200	..	..	..	..	..	..	..	..	..	..	..	..	..	14

It will be readily apparent that the chief point of difference between the fibre produced by these two agaves is the larger amount of short fibres in the blue sisal. This will not, in practice, prove any appreciable obstacle to the increased planting of the new species, since its much greater leaf-length will more than offset this slight disadvantage. By

comparing the curve for sisal with that for sisal after mechanical decortication, the effect of this process can be seen. The shortest fibres are nearly all removed, and some of the longer ones are either removed or are broken. The latter is more probable, since inspection shows that many of these have had portions removed from their ends.

The curve for the length-distribution of the fibres of sisal after

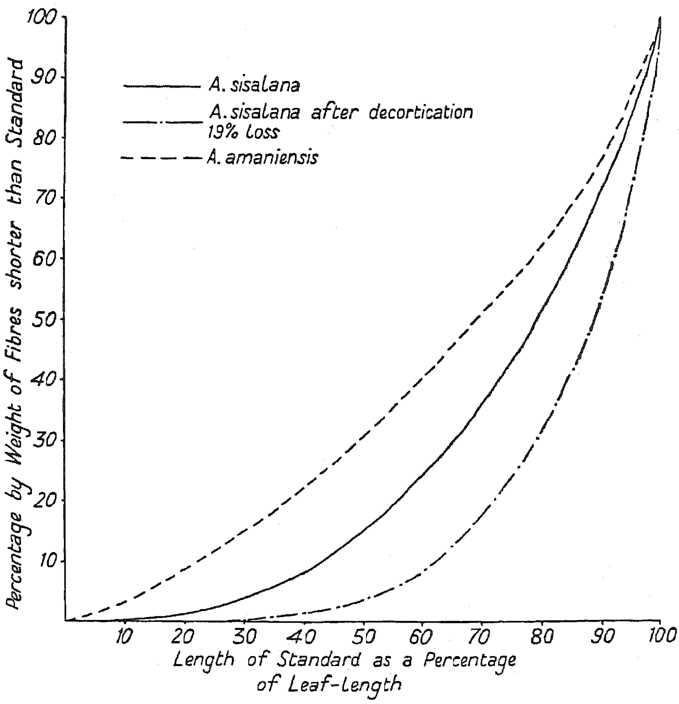


FIG. 9. Relation between leaf-length and percentage of sub-standard fibre.

mechanical decortication happens to be almost exactly logarithmic, with the equation

$$\log x = 3{\cdot}012g/L - 1{\cdot}012,$$

where x is the percentage by weight of fibre below a length g, L being the leaf-length.

Number of fibres per leaf.—This has been studied on sections of the basal end of the leaf. Counts can readily be made at a magnification of about 5 diameters; the mounted section is placed in the negative-carrier of a vertical photographic enlarger, and the fibres can then be classified with ease. Classification has been done as follows: All mechanical fibres of the leaf are dealt with first. M, the result, is the total number of these fibres in the leaf. The ribbon fibres are classified into R_1, the fibres in the median line of the leaf, and R_2, those scattered throughout the ground tissues. RT is the total number of protective fibres. From this is calculated the ratios T/M and M/RT. These figures express the relative amounts of fibres of the two main types in the leaf.

The following tables present some results. The first is of a random selection of *A. sisalana* leaves of various lengths. The second is of a

TABLE 3. *Number and Type of Fibres in Sisal Leaves. (Random Selection of Leaves from Three Localities)*

Length of leaf	*M*	R_1	R_2	*RT*	*T*	*T/M*	*M/RT*
cm.							
73	657	38	82	120	777	1·15	5·5
110	898	45	120	165	1,063	1·16	5·5
118	801	48	92	140	941	1·17	5·7
146	968	52	160	212	1,180	1·22	4·6
98	766	40	78	118	884	1·15	6·5
122	854	50	83	133	987	1·15	6·4
122	822	52	123	175	997	1·21	4·7
123	985	49	159	208	1,193	1·21	4·8
100	655	41	89	130	758	1·16	5·1
86	366	47	72	119	485	1·32	3·1
90	822	45	90	135	957	1·16	6·1
90	685	45	64	109	794	1·16	6·3
90	726	49	76	125	851	1·17	5·8

TABLE 4. *Number and Type of Fibres in Sisal Leaves from One Plant*

	Length of leaf	*M*	R_1	R_2	*RT*	*T*	*T/M*	*M/RT*
	cm.							
1	102	1,077	44	149	193	1,270	1·18	5·6
2	116	1,100	53	139	192	1,282	1·16	5·7
3	122	1,118	45	138	183	1,301	1·16	6·1
4	124	1,089	45	124	169	1,258	1·15	6·4
5	127	1,127	46	130	176	1,312	1·16	6·4
6	132	1,135	48	132	180	1,315	1·16	6·3
7	139	1,200	51	136	187	1,389	1·16	6·4
8	146	1,220	48	141	189	1,409	1·15	6·4
9	150	1,242	48	126	174	1,414	1·14	7·1
10	154	1,127	47	129	176	1,303	1·16	6·4
11	154	1,177	45	103	148	1,312	1·12	7·9
12	151	1,154	47	126	173	1,327	1·15	6·7
13	147	1,048	47	143	190	1,238	1·19	5·5
14	143	1,052	51	138	189	1,241	1·18	5·5
	136	1,133	47·5	132·4	180	1,312	1·16	6·3

series of leaves from an individual plant of the same species, ranging from the lowest leaf on the plant to a young leaf just unfolding from the central bud. The third gives the fibre numbers for leaves of *A. amaniensis*. They are few in number, since it is extremely difficult to obtain satisfactory sections of this species owing to the large number of fine peripheral fibres. It is worth noting that in one leaf of this species, decorticated by hand, a total of 4,524 fibres was counted.

These figures show that there is no close correlation between leaf-

length and the number of fibres, whether the leaves are derived from a number of plants or whether they are all taken from the same plant, although, in general, the longer leaves tend to contain, as might be expected, the larger number of fibres. The relation between the types of bundle in a leaf is surprisingly constant for both species, and affords a ready method of distinguishing between varieties.

The leaf of *A. amaniensis* contains many more fibres than does that of *A. sisalana*, and the proportion of mechanical to ribbon fibres is twice as great in the former. This is of considerable technical importance, as the fibre has quite a different intrinsic make-up, and it seems likely that this difference would have an effect on spinning behaviour.

TABLE 5. *Number and Type of Fibres from Random Leaves of* A. amaniensis

Length of leaf	*M*	R_1	R_2	*RT*	*T*	*T/M*	*M/RT*
cm.							
96	863	32	54	86	949	1·1	10·1
118	1,584	44	81	125	1,709	1·08	12·6
103	1,128	38	58	96	1,224	1·08	12·9
173	2,067	53	147	200	2,267	1·05	10·4

4. *Grading Problems*

The foregoing data have considerable bearing on the problems involved in the grading of the finished commercial product. These problems have come to the fore during recent years, and attempts are now being made, at least in East Africa, to improve and to attempt to standardize the grading of sisal fibre. Neither the producer nor the consumer possesses the fundamental knowledge of the fibre essential to any adequate attack on the practical problems involved. Little information has been available on the fibre as it exists in the plant, as it is commercially shipped, or as it passes through the various stages in manufacture. As a natural result, the personal opinions of both the producer and the consumer have become elevated to the rank of dogma.

Before considering grading in detail, it is advisable to assess the range of leaf-length which is normally attainable on a well-run commercial estate. Table 6 presents the results of leaf-measurements on a number of estates (A–D), all situated on the East African coastal plain. It should be emphasized that these do not represent areas where either very short or exceptionally long leaf is normally encountered. They are good average estates, with the exception of Estate A, which enjoys an enviable reputation for the excellence of its product. The distribution X was specially chosen for exceptionally long leaf; few coastal estates average such a high figure as 110 cm. The distributions are all taken over one complete day's cut, chosen as far as possible to include leaf from a part of the estate where conditions are not extreme in any way. Adequate randomization of the leaves measured is readily done

by taking leaves at random from the rapidly moving belt on which they are carried to the decorticator.

The basis of grading in the past has been very ill defined and, with the high prices formerly prevailing for sisal fibre, coupled with the constant demand, little incentive to improvement existed. With the onset of the depression in the early 1930's the position changed. Low prices and lack of demand caused the growers to seek improved methods of preparation and better grading. Even so, the majority of estates grade on the old basis.

TABLE 6. *Frequency Distributions of Leaf Length on certain East African Sisal Estates*

Length of leaf	*Estate*				
	A	*B*	*C*	*D*	*X*
cm.					
45–50	..	..	..	5	
50–55	..	..	2	19	2
55–60	2	1	9	42	2
60–65	1	7	19	84	4
65–70	7	15	50	106	8
70–75	15	34	60	119	9
75–80	27	81	73	107	6
80–85	49	111	84	123	8
85–90	44	122	79	116	11
90–95	72	89	54	74	16
95–100	80	71	44	31	15
100–105	74	40	18	36	22
105–110	67	37	..	30	32
110–115	74	13	..	20	32
115–120	47	3	..	9	36
120–125	22	4	..	4	40
125–130	11	..	..	..	17
130–135	4	..	..	..	20
135–140	2	..	..	..	8
140–145	1	..	..	..	3
145–150	0	..	..	..	3
150–155	1	..	..	..	2
155–160	..	..	..	..	2
160–165	..	..	..	..	1
165–170	..	..	..	..	2

The sisal leaves are passed into the decorticator arranged transversely on a long conveyor belt, 30 ft. or so in length. A gang of natives is stationed beside this belt, arranges the leaves on it, and is supposed to remove all broken, discoloured or damaged leaves, as well as all below a certain length. The type of labour usually assigned to this work is not particularly intelligent, and hence judgement is often faulty.

It is easily shown by experiment that judgement of any quantity is affected by the average of the sample under examination. Thus in grading leaves by eye for length the grading will be much less severe when the average length of the sample is low, e.g. when grading leaves of an average length of one metre an individual 70 cm. long might pos-

sibly be rejected. If the average dropped to 80 cm. it is improbable that such a leaf would be culled. Obviously such a practice will cause considerable variation in the length-range of fibre shipped under one grade mark by different estates, as the length of the leaf being decorticated will vary with the length of leaf produced on each estate. For example the difference in composition of the fibre from four *good* estates, all shipped under one grade mark, is given below.

The figures refer to the number of fibres (expressed as a percentage of the total for each estate) shorter than the lengths appearing at the head of each column.

TABLE 7

	Length of fibre in cm.													
Estate	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*	*110*	*120*	*130*	*140*
A	0	0·4	0·5	1	3	10	19	31	44	57	76	92	99	100
B	0	0·1	1	3	4	7	24	36	46	56	64	69	83	87
C	0	0·1	1	1	8	13	24	34	50	54	62	75	89	98
D	0·3	1	4	9	14	24	34	46	59	70	84	92	95	99

Even on these selected estates it will be seen that the percentage number of fibres less than, say, one metre in length varies from 54 to 70 per cent. Had fibre from estates which normally produce a shorter leaf been included, the figures would have been more striking. One estate, producing sisal fibre which is mostly graded as No. 1, and experiencing no particular difficulty over length arbitration, has nearly 98 per cent. of its fibre shorter than one metre.

It is quite possible that this inefficiency in grading is the cause of the practice of the consumer to buy fibre on estate marks, and not on the grade. Although methods of preparing the fibre vary somewhat from estate to estate, and some factories admittedly turn out a product of superior appearance, yet I think that the main reason for the known preference of the consumer for certain marks is the estate-to-estate variation in the length-distribution of the fibre.

It is obvious that grading by some mechanical device will necessarily supersede the methods now in vogue. One such grader is in operation in East Africa at the time of writing, and performs its task by estimating the leaf-length during the process of decortication, and delivering the fibre from under-grade leaves on a separate conveyor-belt. By this means all the leaves are fed into the decorticator irrespective of length, and the factory does not become cluttered up with masses of rejected leaves. In my opinion such a method is the only one practicable at present, or, so far as we know, desirable. An estate, with no major alteration in its organization, can produce grades of fibre guaranteed to be from leaf none of which is below a fixed minimum.

A point which is not sufficiently kept in mind is that such a grade will contain fibres of a wide range of lengths, however uniform the leaf-length may be. Each leaf will contain its complement of long and short fibres, and only a portion of the latter will be removed in decortication.

The weight-distribution of fibres of various lengths after decortication can be obtained from the equation on p. 83.

On certain estates a system of grading is in force which appears to produce a more uniform product, and which has the advantage that a certain proportion of fibre is appreciated in grade. In other words, much fibre, correctly classifiable as No. 2, will be concealed among fibres of greater length and will innocently be sold as No. 1. The system is as follows: after each hank of fibre has been brushed, it is passed to boys who pack it into crates prior to baling. As each hank is handled it is measured, and any shorter than standard is degraded. This method would appear, at first sight, to be adequate but is not so in fact.

The sisal leaves pass into the decorticator in a random manner, the fibres from a *number* of leaves being bundled together at the exit end of the machine. This aggregate of separate hanks passes through the drying and brushing processes as a unit, and, after brushing, the individuality of the hanks of fibre from each leaf is lost. Hence, after brushing, grading is carried out on a bundle of fibres originating in several leaves, some of them possibly being short, and each carrying its complement of long and short fibres. The grading, of course, is dependent on the length of the *longest* leaf, and hence, although the appearance of uniformity is achieved, the grading is more apparent than real. Analysis of material graded by this method and of ungraded controls shows no appreciable improvement.

We have so far considered sisal-grading on the basis of leaf-length. Each grade is fibre produced from leaf of a given minimum length, each leaf contributing its complement of long and of short fibres to the final product.

There is, however, a recent tendency to attempt to grade sisal fibre on the basis of a minimum *fibre*-length. The initiative in this direction has apparently come from the spinners, who claim that a minimum fibre-length (3 ft. being suggested as a reasonable length for No. 1 fibre) is necessary for efficient manufacture. This may well be true, but I am unaware that any evidence exists on which this statement is based, nor does any attempt appear to have been made to confirm it by experimental means. It is quite certain that, at any rate up to 1935, no spinning has been done with sisal graded on the basis of a reasonable minimum fibre-length, nor had such a material been prepared. In the absence of evidence as to the desirability of such a product, the necessity for grading on the new basis will depend on the state of the markets and the firmness or otherwise of the buyers' demand for a product of which they have, as yet, no experience.

It may be possible to combine grading on the basis of a minimum fibre-length with the process of decortication. A decorticator operates somewhat as follows. The leaf is gripped, near the butt end, at right-angles to its length, by a moving system of ropes and pulleys. The longer portion passes over a concave plate, where it is subjected to the scraping action of a knife-armed revolving drum. During this process some of the fibre is broken and lost. The grip is then shifted to the fibre as delivered by the first drum, and the remaining portion of the leaf is treated in a similar manner by a second drum.

It will be seen that the knives of the second drum are scraping towards the butt end of the leaf, and any fibre shorter than the distance from the butt to the point where the fibres are gripped by the ropes will be torn away and lost. Certain other fibres are also torn and destroyed.

It will be apparent that any increase in the severity of decortication, whether produced by the slowing up of the feed so that the leaves are subjected to the pulling action of the knives for a longer period, or by the setting of the knives closer to the concave face whereby the pulling action is intensified, will result in an increase of the proportion of fibre removed from the grip of the ropes or broken up and torn apart. The distance from the butt of the leaf to the point where the ropes grip it will also affect the amount of fibre stripped, since any increase in this distance will leave more fibre ungripped on entry of the leaf into the second drum of the decorticator. A recent improvement in decorticating machinery consisted in moving the grip close to the butt end of the leaf, so that the shorter fibres are nearly all retained. From one point of view such an alteration represents a distinct advance, since the amount of waste fibre is reduced. From another it is retrograde, since the amount of short fibres in the finished product is increased.

It is therefore theoretically possible so to arrange the severity of decortication that only fibre above a fixed minimum length is delivered by the machine, the remainder of the fibre passing into the waste flumes. Claims have been made that such a process is being worked on a commercial scale.

On estates decorticating in the normal manner the amount of fibre going to waste is generally about 20 per cent. of the total fibre in the leaf. This is complete waste, and no attempt is made to recover any of the lost fibre. When decortication is carried out for a minimum fibre-length this waste will be proportionately increased, and it will become desirable or necessary to extract the shorter fibre from the waste-flumes, and to bale and sell it separately. It is claimed that machinery exists capable of doing this.

To determine with some accuracy the amount of fibres of various length produced over a period of time on a commercial estate the following measurements were carried out with the co-operation of the manager of the estate in question, which produces leaf rather longer than the average. The distribution X in Table 6 actually came from this estate.

Ten leaves were taken at random from the conveyor belt daily over an interval of 3 months and measured. Table 8 presents the results, and Fig. 10 shows the distribution of length of leaf as produced by the estate. From these data it is possible to calculate the composition of the fibre in the leaves. The weight of fibre per leaf is approximately proportional to the weight of the leaf, which in turn is proportional to the length. Column 3 in the table gives the observed class-frequencies. Taking the amount of fibre contained in a leaf 100 cm. long to be unity, column 4 gives the factor by which each class-frequency must be multiplied to give a figure representing the weight of fibre in each class. Column 5, therefore, gives the *relative* weights of fibre produced by the leaves of each length-class.

As we know (from the equation on p. 83) the percentage distribution of fibre of any length as produced by normal decortication of leaves of any length, it is possible to calculate, as in the remainder of the table, the amounts of fibre of various lengths produced by each length-class of leaves. By vertical summation the amounts of fibre of each fibre-length class given by the whole crop of leaves can be ascertained and expressed as a percentage of the total.

Fig. 11 shows the distribution of the fibres by length. It will be seen that the fibre-distribution curve is much more skew than that for leaf-length. The reason for this is that all the leaves yield their contribution of short fibres to the total, whereas only the long ones contribute long fibres. Thus, after the 80–90 cm. class the percentage falls off rapidly, the percentage by weight of fibres shorter than 110 cm. being 97·6 per cent. of the total.

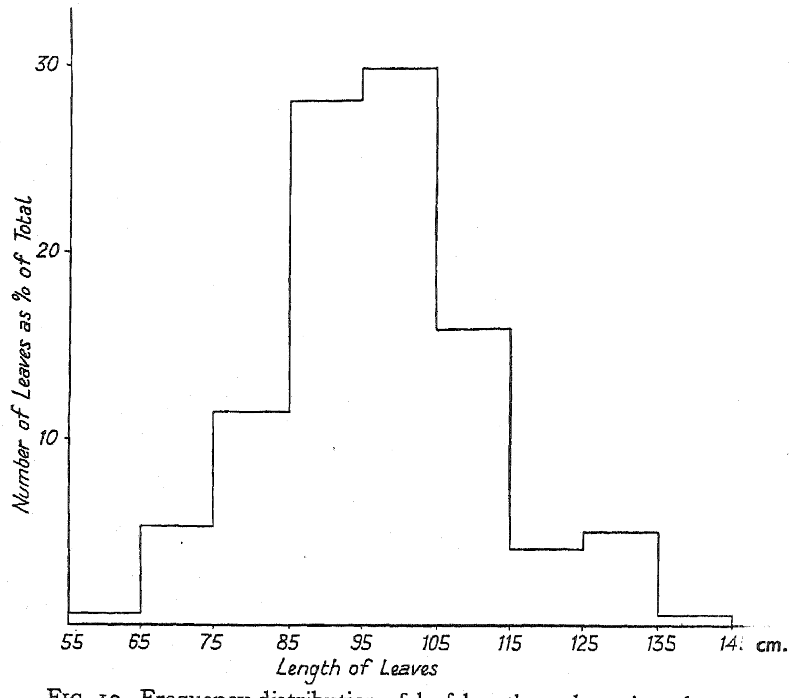


FIG. 10. Frequency distribution of leaf-length as decorticated over three months on a sisal estate.

Although certain selected areas might possibly produce such a long leaf that the percentage of waste (when the fibre is graded on the basis of a reasonable minimum fibre-length) would be reduced to a practicable figure, it does not appear that the majority of sisal-growing areas will find it possible to grade on this basis unless some other agave is substituted for *A. sisalana*. The use of *A. amaniensis* may conceivably solve this problem, since for a leaf-length of 180 cm. the waste would be less than 30 per cent. grading on a 3-ft. minimum fibre-length. This length of leaf is, so far as our experience with this plant goes, likely to be

Table 8

Length of leaf cm.	*Class average*	*Frequencies*	*Factor for weight correction*	*Weight of fibre per class*	*Proportional weight of fibre in each fibre-length class and in each leaf-length class*													
					0–10 cm.	*10–20 cm.*	*20–30 cm.*	*30–40 cm.*	*40–50 cm.*	*50–60 cm.*	*60–70 cm.*	*70–80 cm.*	*80–90 cm.*	*90–100 cm.*	*100–110 cm.*	*110–120 cm.*	*120–130 cm.*	*130–140 cm.*
55–65	60	3	0·6	2	2	8	20	34	50	86								
65–75	70	27	0·7	19	19	57	132	209	304	475	704							
75–85	80	58	0·8	47	..	94	233	372	558	696	1,163	1,535						
85–95	90	142	0·9	128	..	128	512	768	1,152	1,410	2,050	2,945	3,840					
95–105	100	151	1·0	151	..	151	455	756	1,057	1,510	1,660	2,415	3,320	4,070				
105–115	110	80	1·1	88	..	88	176	264	440	704	792	968	1,320	1,935	2,112			
115–125	120	20	1·2	24	..	..	48	72	96	114	168	240	264	360	480	528		
125–135	130	25	1·3	34	..	..	34	102	102	170	187	272	306	340	510	646	714	
135–145	140	2	1·4	3	..	..	3	6	9	12	15	18	24	27	33	45	51	57
Totals	.	.	.	.	21	526	1,613	2,681	3,768	5,209	6,739	8,395	9,074	6,732	3,135	1,219	765	57
					Weights of fibre as percentages of the total fibre													
					0·04	1·05	3·23	5·18	7·56	10·45	13·52	16·85	18·21	13·51	6·29	2·45	1·54	0·14

attained under the conditions prevailing over the greater part of the sisal-growing areas in Tanganyika.

It is also to be noted that the longest fibres are the coarser in any leaf. By removing the shorter fibres a coarser product will result. Only

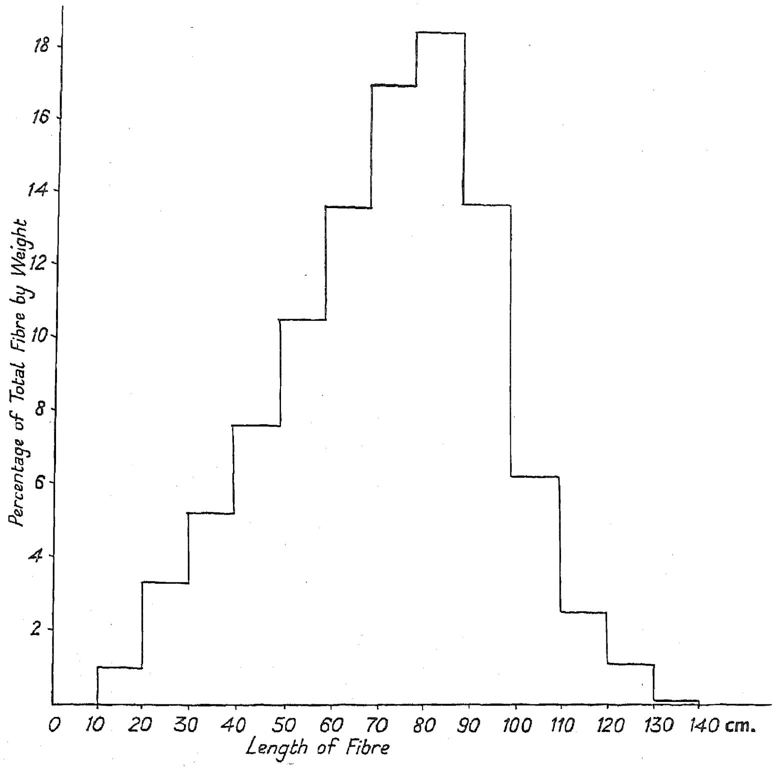
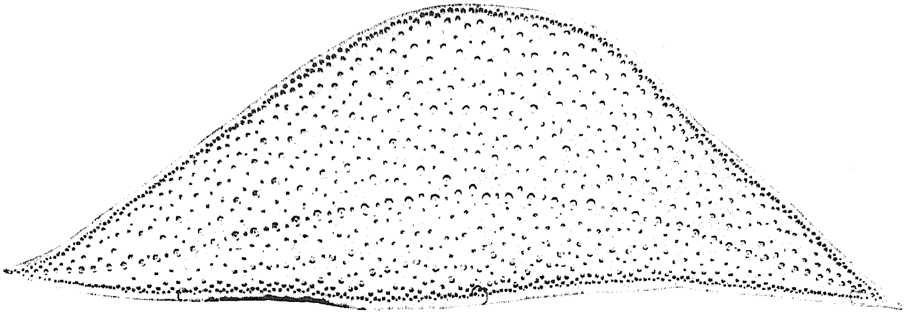


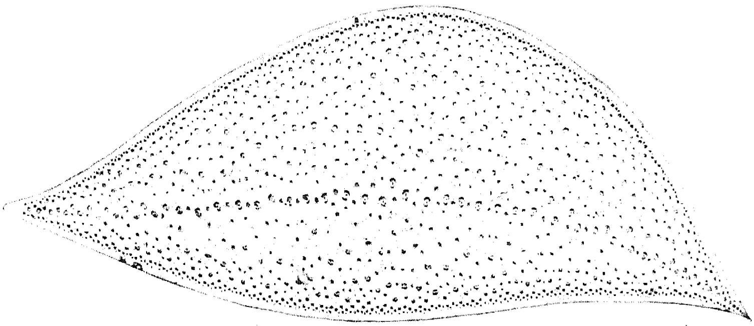
FIG. 11. Composition of three-months fibre-production on a commercial estate *A. sisalana*

adequate experimentation will decide whether a coarse, long, uniform fibre is to be preferred to the fibre as it is at present shipped. Even so, an essential preliminary to any grading on a fibre-length basis by the producer would appear to be the determination, by the consumer, of his actual requirements. It is useless for a primary producer to embark on ambitious grading schemes, even if these are practicable, until he knows that the product is, in fact, that which is required by the market. This information is not yet forthcoming.

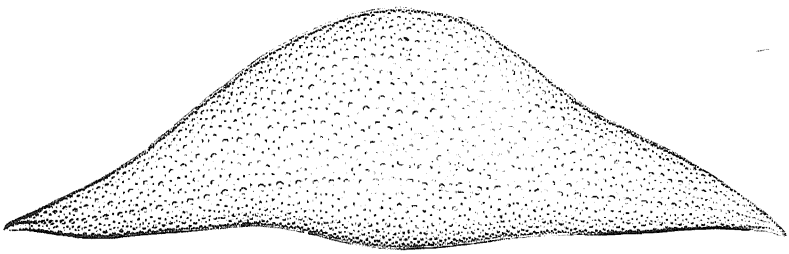
(*Received July 16, 1936*)



A. sisalana

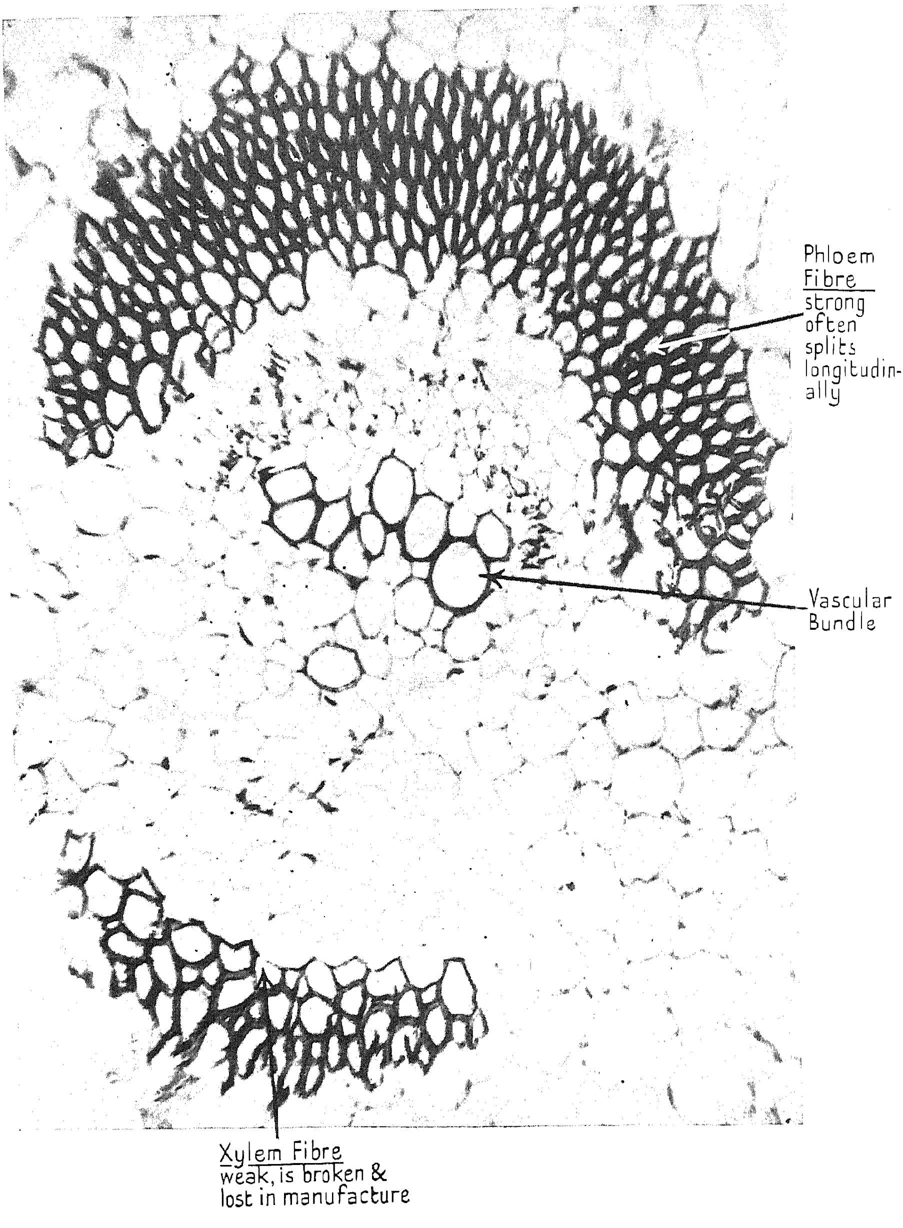


A. cantala

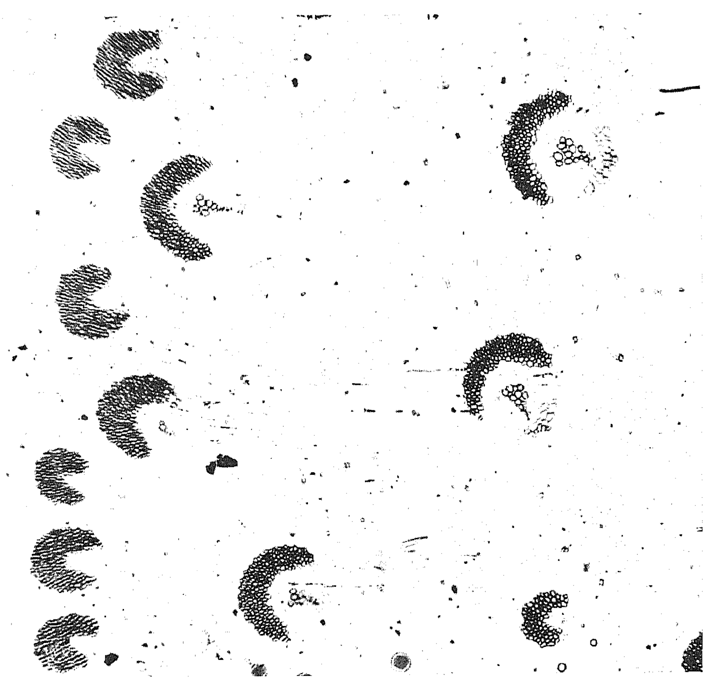


A. amaniensis

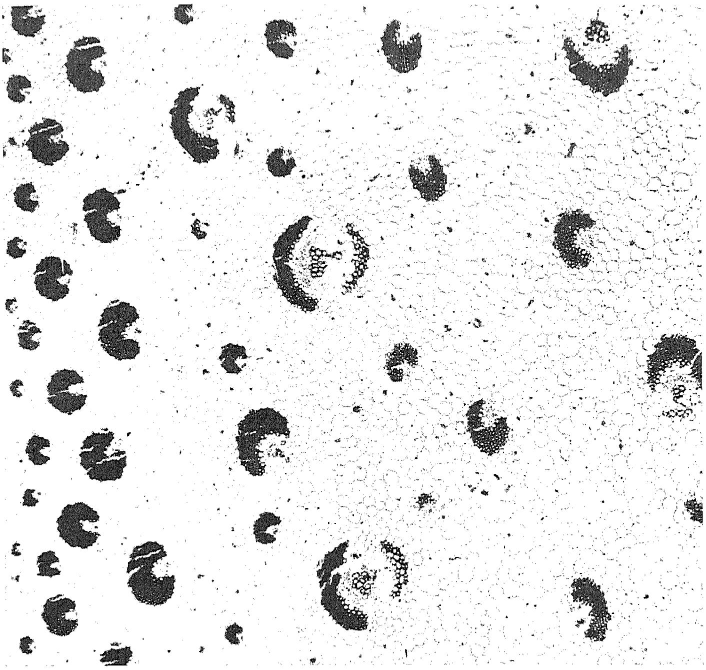
Transverse sections ($\times 1\frac{1}{2}$) of leaves of *Agave sisalana*, *A. cantala*, and *A. amaniensis*



One of the median line of 'Ribbon' fibres in *Agave sisalana*



Agave sisalana × 32



Agave amaniensis × 32

Sections of portions of leaves of *A. sisalana* and *A. amaniensis* under the same magnification. Note the larger number of smaller denser peripheral bundles in the later species. All types of fibres are shown in both sections

AGAVE FIBRES

Pt. II. MECHANICAL QUALITIES

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Agave fibres have been and still are mainly used for the somewhat unexacting purpose of making binder and similar twines. Recently, however, they have been more widely taken up for the manufacture of finer twines, and for rope-making. For such uses, especially for marine cordage, the mechanical properties of the fibre are important.

Little work appears to have been done on this subject. Braun [1] made some strength tests in East Africa, but his results are valueless owing to the small number of fibres tested. According to Barker [2], Dantzer and Roehrich have worked on the mechanical properties of sisal fibres, and their methods and results are somewhat sketchily summarized by him. These, as quoted by Barker, differ widely from the results reported here, and no indication is given as to the degree of accuracy attained.

The methods to be described have been developed in Amani to aid in the selection of promising varieties; and for this purpose they must be both accurate and readily reproducible. It has been found that enormous numbers of tests are necessary if the results are to be of any value, and also that scrupulous care must be taken in the randomization of the test-material. Procedure must also be standardized and rigidly followed.

Position of test portion.—Some leaves were decorticated by hand, the fibres measured and sorted into length-classes, and each fibre tested for tensile strength at 10 cm. intervals along its whole length. For all fibres the resultant curve of strength was of the same type, that is to say, a hyperbola. The position of maximum strength is approximately one-third of the distance from the butt end, and the strength falls off uniformly on each side of this point.

Fig. 1 shows, graphically, the relation between the length of the fibre and the tensile strength in grams at this point. It is a straight line.

If the point of maximum strength on fibres of all lengths be expressed as percentages of the maximum strength, then (plotting the points of testing as percentages of the total length of each fibre) all the points lie closely on one hyperbola. This is shown in Fig. 2. The equation of a (freehand) curve drawn through these points is

$$(100x/M+3\cdot6)^2-(100y/L-36)^2 = 3\cdot6^2,$$

where x is the breaking-strain recorded in grams at a point y cm. from the butt end of a fibre of length L cm., the maximum breaking-strain at any point on the same fibre being M gm.

Although most desirable, it is obviously impracticable to test each fibre at this point, because in sampling it is necessary to select some point on the hank of fibre for the test portion. The middle is unsuitable, since we have seen that the fibre of sisal contains a large proportion of

fibres less than half the length of the maximum, which would thus be ignored.

The test portion has been standardized as that part of the *hank* lying between 20 and 30 cm. from the butt end. If, as in Fig. 1, the relation between fibre-length and the breaking-strain at 25 cm. from the butt end be inserted, the two straight lines intersect at a fibre-length of 75 cm. This is almost exactly the average fibre-length on a first-class commercial

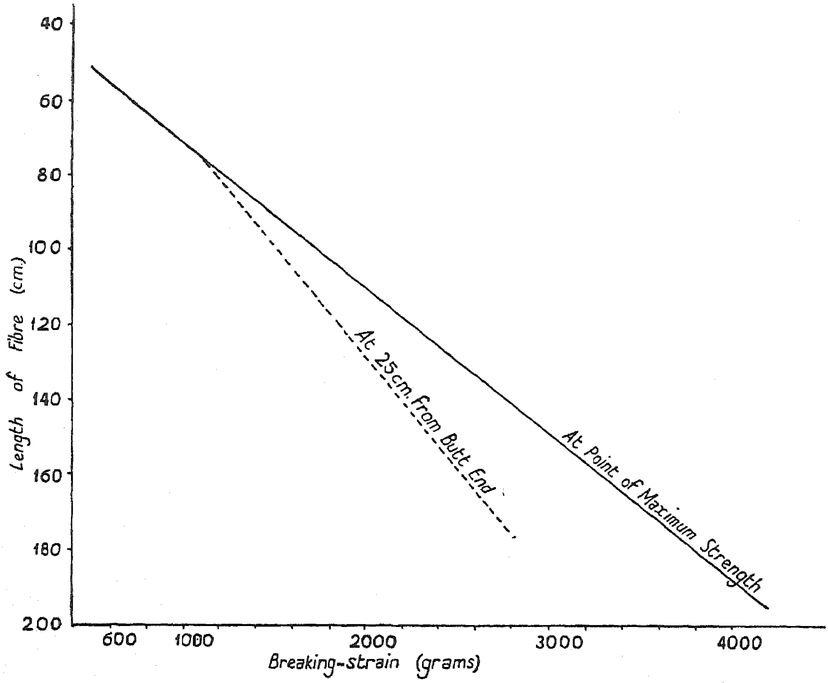

FIG. 1. Relation between length of fibre and breaking-strain in *Agave sisalana*.

estate. By choosing the test portion at this point most of the short fibres are included. The majority of fibres are tested at, or near, their point of maximum strength; and certain of the longer ones are tested towards their basal end. Admittedly this selection of the position of the test portion is open to certain objections, but it is the most suitable position when the choice is made with reference to the hank of fibres and not to the individual fibre. A number of samples comprising about 6,000 fibres each were cut from a hank of fibre at 20–30 cm. from the butt end, trimmed to 5 cm. in length, and tested for tensile strength. Every fibre was broken upon a machine to be described later. Some of the results are given in Table 1.

The frequency distributions are not quite normal, but are near enough thereto for enabling the appropriate size of sample to be selected for routine testing. The main statistics of three of these samples are presented in Table 2, and serve to indicate the degree of uniformity attainable.

TABLE 1. *Frequency Distributions of Breaking-strain of Sisal Fibre from Six Localities*

Grams	*A*	*B*	*C*	*D*	*E*	*F*
0– 100	28	37	0	..	17	18
100– 200	39	22	0	10	27	63
200– 300	43	52	7	9	23	68
300– 400	42	132	19	10	88	82
400– 500	60	182	87	26	82	67
500– 600	126	222	102	33	297	137
600– 700	112	197	213	38	289	188
700– 800	168	302	242	63	332	178
800– 900	230	333	328	76	322	318
900–1,000	234	336	330	73	342	280
1,000–1,100	250	327	243	79	360	325
1,100–1,200	228	340	278	84	368	282
1,200–1,300	220	340	265	113	393	297
1,300–1,400	216	312	218	105	395	252
1,400–1,500	193	287	209	125	337	282
1,500–1,600	218	327	225	106	324	257
1,600–1,700	130	332	184	91	342	247
1,700–1,800	157	262	117	69	345	268
1,800–1,900	132	292	172	73	289	288
1,900–2,000	103	202	262	63	230	282
2,000–2,100	89	217	200	45	248	192
2,100–2,200	102	258	240	73	236	202
2,200–2,300	32	202	140	46	218	92
2,300–2,400	47	135	110	37	59	137
2,400–2,500	28	137	78	39	83	77
2,500–2,600	39	82	128	37	70	92
2,600–2,700	10	23	82	14	84	72
2,700–2,800	13	97	93	14	100	68
2,800–2,900	..	72	..	9	..	22
2,900–3,000	..	33	..	21	..	126
3,000–3,100	..	..	..	8	..	41
3,100–3,200	..	..	..	2	..	156
3,200–3,300	..	..	..	1	..	..
3,300–3,400	..	..	..	3	..	..
3,400–3,500	..	..	..	0	..	..
3,500–3,600	..	..	..	0	..	..
3,600–3,700	..	..	..	7	..	..
3,700–3,800	..	..	..	7	..	..
3,800–3,900	..	..	..	8	..	..
3,900–4,000	..	..	..	11	..	..

TABLE 2. *Samples from Three Estates*

	1	*2*	*3*
n	6,100	6,092	5,456
x	1,403 gm.	1,414	1,528
s	656·9	632·8	710·2
S.E. of mean . .	8·4	8·0	9·0

From this it is apparent that the standard errors of the means of the samples, expressed as percentages of their respective means, are as shown in Table 3, assuming that the smaller samples are drawn from adequately randomized material.

TABLE 3. *Standard Errors of the Determination of the Breaking-strains of Samples of Sisal Fibre of Varying Size, expressed as Percentages of the Mean. For Sisal from Three Estates*

Number of fibres in sample	*Estate*		
	1	*2*	*3*
100	4·7	4·5	4·6
600	1·9	1·8	1·8
1,000	1·5	1·4	1·4
6,000	0·6	0·6	0·6

It was therefore decided to fix the size of the sample taken for routine testing as between 600 and 1,000 fibres. With this number, and provided that the variances of the smaller samples were approximately the same as those of the larger ones, differences of 100 gm. in the means of samples will be significant. The variances are, in fact, of the same order as those given here.

Randomization of the sample.—With such heterogeneous material as we have seen sisal fibre to be, adequate sampling-technique is essential, and more difficulties have been experienced with it than with any other problem connected with this work. Shuffling by hand has been proved to be useless, since it is much affected by the tendency of sisal fibres to adhere together, and for aggregates to pass undisturbed through shuffling processes, even when the fibres are but 5 cm. long.

After many mechanical mixing devices had been tried and discarded, it was found that if the fibres are placed in a cylindrical jar arranged to rotate with its axis horizontal, randomization is attained. The correct speed of rotation is just below that at which the fibres are pressed against the side of the jar by centrifugal force. They are carried up nearly to the top by the rotation, and then fall almost vertically to the bottom. Eventually a loop of lightly felted fibres rotates inside the jar, but at a different relative speed. The fibres in the loop constantly change their relative position, and in this manner randomization is obtained.

Adequate mixing was achieved in two hours. Four hours, therefore, has been standardized as the period during which the sample is mechanically shuffled.

The sampling-technique finally decided upon, and now in use as a routine procedure, is as follows:

1. From the bulk of fibre, small hanks are taken at random until a sample of about 5,000 fibres has been secured.

2. The butt ends of these are placed together, and the portion between 20 cm. and 30 cm. from this end is cut out. The remainder is discarded.

3. These short fibres are tied into about 50 smaller bundles with sewing cotton.

4. Each bundle is trimmed to exactly 5 cm. in length, approximately equal amounts being removed from each end. The error involved in this trimming to length has been shown to be less than 1 per cent.

5. All the fibres, unbound, are placed in the cylindrical jar and rotated for four hours at the correct speed.

6. From the mixed and randomized sample 6 sub-samples are taken, each containing from 100 to 200 fibres. These are tied in bundles and labelled for testing.

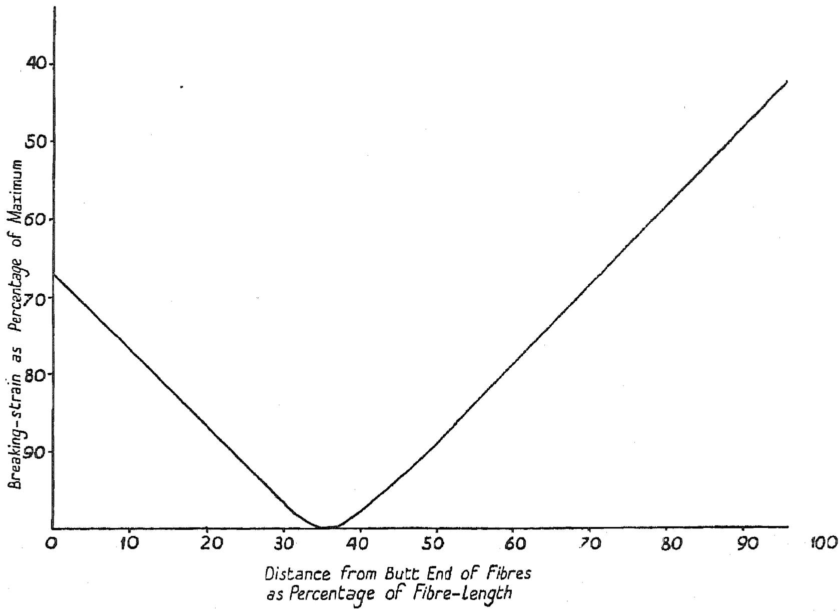

FIG. 2. Distribution of breaking-strain along the fibres of *Agave sisalana*.

7. Each bundle is weighed to the nearest milligram on a torsion-balance.

8. The fibres from each bundle are tested individually for tensile strength on a testing-machine, and the results recorded on a frequency diagram.

Owing to the very great inherent variability of the test-material it is not claimed that this method will give complete randomization in every case, when the number of fibres in each test is 600–1,000. It is, however, the best method yet devised; it is practicable; and it can usually be shown that the differences between the means of the six sub-samples are not statistically significant.

The testing-machine on which all tensile-strength tests have been carried out was made locally. In principle it conforms to normal design, the pulling up of a weighted arm by the fibre applying an increasing strain to the latter. After breaking has taken place the arm is held in position against a graduated arc by means of a trailing pawl. The cam at the top of the arm is cut to a $\frac{\sin\theta}{\theta}$ curve, so that equal distances along

the arc traversed by the arm correspond to equal increments in strain. This also ensures that the rate of loading shall be constant.

The fibre is gripped, at each end, between brass plates tightened by a thumbscrew. The bottom grip is attached to a split nut, engaging with a vertical threaded rod, rotated by a constant-speed motor through a reduction-gear. This grip is thus pulled downwards at a speed corresponding to a rate of loading of 3·5 kg. per minute. The length of fibre between the grips is 3·5 cm. It is of great importance that this distance be kept constant, as the value of the figure for tensile strength varies with the length of the fibre under test.

Readings are made to the nearest 100 gm., smaller intervals being unnecessary owing to the heterogeneous nature of the material under test. After the reading has been taken the grips can readily be returned to their original position by lifting the trailing pawl, allowing the weighted arm to drop, and opening the split nut, which can then be slid up to the top of the threaded rod.

The machine is very heavily and robustly made, as it is largely used by trained Africans. It has given satisfactory service for five years, over half a million fibres having been broken. The only replacements necessary have been the thumbscrews, which become worn after a few months' use.

At the end of each test the following information is available, for each of the six sub-samples:

1. The weight in milligrams of the bundle, w.
2. The number of fibres in the bundle, n.
3. The average breaking-strain in grams, s.
4. The frequency-distribution of the breaking-strain.

From these data the following standards are calculated:

A. The fineness of the fibre, F. $F = 2w/n$.

Dantzer and Roehrich express the fibre-fineness as the 'metric number', which is defined as the length of the fibre in kilometres weighing one kilogram, i.e. $\frac{50n}{w} \times 10$. There appears to be no adequate reason for their choice of the reciprocal expression, and we have substituted the direct measurement of weight per unit length. For convenience this is expressed as the weight in milligrams of a 10 cm. length of fibre.

B. The breaking-strain, s. This is recorded directly in grams.

C. The breaking-length, L. $L = sn/20w$.

This standard has been defined by Dantzer and Roehrich as the length of fibre which, if held up by one end, would break under its own weight. It has been retained, as a real quality of the fibre is expressed, and a correction of the figures for tensile strength is made for the varying fineness of the fibre.

It is bound to tend towards constancy in that one number (s) is multiplied by the reciprocal of another (F), which is itself correlated with the first, as it is obvious that in general a finer fibre will have a smaller breaking-strain than a coarse one. Even so, the small differences found

in practice between the breaking-lengths of different samples can be shown to be statistically significant. These differences express, one presumes, some differential arrangement in the fibrils, or some difference in the intrinsic quality of the fibre-material in two differing samples of fibre.

The accuracy of the determination of the breaking-length was determined by weighing and breaking fibres individually. The results were:

$$n = 116 \quad \bar{x} = 30{\cdot}68 \quad s = 8{\cdot}846 \quad \text{S.E. mean} = 0{\cdot}788$$

For a sample of 1,000 the S.E. of the mean will be 0·269 or 0·86 per cent. Therefore, for the size of samples usually taken, differences in the breaking-length of one or more will be significant.

TABLE 4. *Strength Characteristics of East African Sisal*

(Each figure is the average of sextuplicate determinations comprising a total of about 1,000 fibres)

Area	Weight in mg. per 10 cm.	Breaking-strain gm.	Breaking-length km.
First cuts			
Magunga	2·99	1,245	41·6
Makinyumbe	2·86	1,210	41·6
Kilifi	2·93	1,614	56·4
Thika	4·47	1,956	43·6
Ngombezi	3·76	1,842	49·6
Pongwe	3·41	1,140	33·6
Moa	4·49	1,678	38·2
Korogwe	3·13	1,741	54·9
Mwera	3·11	1,592	51·6
Second cuts			
Magunga	3·16	1,184	37·4
Makinyumbe	3·24	1,332	41·2
Kilifi	3·92	1,562	39·9
Thika	4·39	1,813	41·8
Moa	3·49	1,669	48·4
Third cuts			
Magunga	2·97	1,189	40·1
Makinyumbe	3·29	1,400	42·5
Thika	3·29	1,869	43·6
Pongwe	2·97	1,094	39·6
Moa	3·38	1,905	48·9
Taveta	4·68	1,706	36·9
Mwera	4·67	1,785	38·4

Samples of sisal fibre were obtained from the bulk product of ten estates, and where practicable the samples were selected by me personally. Each sample was tested in accordance with the methods described. A general summary of the results is given in Table 4. Detailed results for the fibre from each area have been filed in the archives for biological measurement at the Natural History Museum, South Kensington.

These figures form the background necessary for any review of fibre-data in general. We see that the average breaking-strain of commercial

sisal fibre can vary between 1,100 and 2,000 gm., that the fineness varies from 2·8 to 4·7, and the breaking-length from 34 to 56. There does not appear to be any marked correlation between fineness and breaking-length or between breaking-strain and breaking-length. In addition, no general relationship is apparent between the age of the plant and the mechanical properties of the fibre produced.

There are, however, indications that the properties of the fibre are correlated with the area producing it. *Thika* fibre is grown in the Kenya Highlands, and it is notably coarser and stronger than usual. *Taveta*, also distant from the coast, and at an intermediate altitude, is almost as strong and coarse.

The areas *Magunga* and *Makinyumbe* are adjacent, and the characteristics of fibre from both are similar. *Ngombezi* and *Korogwe* are also associated by similarities of fibre-characters, both showing moderate fineness, and high values of both breaking-strain and breaking-length. They also are fairly close together. Actually the two former are situated on the east side of the Luengera valley, on greyish sedimentary and transported soils. The latter two are on the other side of the valley, and on a fundamentally different soil type, derived *in situ* from a parent rock, and in general better drained, redder, and of higher phosphate-content.

The above conclusions are only very tentative. Insufficient is known about the exact sites of the sources of the fibre-samples reported on here for any generalizations to be drawn. Their main purpose is to exhibit the values of the fibre-qualities as measurable under the conditions stated; to show the range of variation in the commercial output of sisal estates in East Africa; and to form a basis of comparison for future work.

The following table represents the results of tests of other fibres:

TABLE 5

	Fineness F	*Breaking-strain* s	*Breaking-length* L
Java *Cantala* A Commercial sample	2·29	791	35·1
Java *Cantala* X Commercial sample	2·16	854	39·3
Java *sisal* A Commercial sample	2·00	1,482	76·8
Java *sisal* X Commercial sample	2·29	1,302	57·5
A. amaniensis Second cut	2·62	1,001	39·1
A. amaniensis Third cut	2·20	984	45·3

I have included the results of the samples of Java sisal in this table as they are of particular interest. The sample from which the figures were obtained had been specially selected, and, I suspect, specially treated. The figures for fineness are enough to render the genuineness of such a sample suspect, since they are finer than the corresponding samples of

Java *cantala* and also finer than *A. amaniensis*. The last two determinations are of blue sisal, prepared at Amani. They show quite clearly the fine character of the fibre. The intrinsic strength, as shown by the result for breaking-length, is high, and considerably above the average for sisal. The figures as given here are probably too low, since the much greater leaf-length of this species makes the standard position of the test-portion somewhat unsatisfactory, the majority of the fibres having been tested towards their weaker end.

Relation between fineness, breaking-strain, and cross-sectional area of fibre.—From a randomized sample of fibre, individual fibres were taken, each weighed separately on a micro-balance to the nearest 0·01 mg., and 1 cm. removed from one end. This short piece of fibre was cut across again as nearly as possible at right angles to its length with a very sharp razor, and mounted in an upright position on a wax-covered microscope slide. By means of a powerful spot of light thrown on the fibre it was found possible to project an enlarged image of the cut end epidiascopically. This was drawn and measured with a planimeter. The remaining 4 cm. of fibre was broken on the testing-machine in the normal manner. The results of 44 such tests are given in Table 6.

From inspection of these figures it is apparent that the weight per unit length of fibre (F) is correlated with the cross-sectional area of the fibre (A) and also with the breaking-strain (s).

These correlations are all positive and significant.

r_{12}, weight per unit length and area $= 0{\cdot}9432$.
r_{13}, weight per unit length and breaking-strain $= 0{\cdot}5603$.
r_{23}, area and breaking-strain $= 0{\cdot}5662$.

$$\text{for } n = 44 \quad P = 0{\cdot}01 \quad r = 0{\cdot}3932$$

These figures differ from those given by Barker for similar determinations by Dantzer and Roehrich. Their figures for tensile strength per sq. mm. of fibre-substance vary from 72 to 93. The result is possibly explained by the shortness of the test-length used by them. Their values for the density of sisal vary from 0·785 to 0·845, as against $0{\cdot}752 \pm 0{\cdot}031$ for the same measurement at Amani. This discrepancy may be explicable on the ground that they determined the density by measuring the volume of fibres under a pressure of 2 kg. per sq. mm. Considerable compression must take place, and it is thought that the figures here, being based on direct determinations of weight and volume, are the more accurate.

The result for the tensile strength of the substance of the fibre is of some interest. An assumption made during the calculation is that the density of the fibre-substance is 1·5, as for all cellulose fibres. This probably approximates to the truth. The result is probably a *minimum* value, since the breaking-strain is bound to be a minimum. Under the conditions specified the intrinsic strength for the whole 44 determinations is $56{\cdot}8 \pm 3{\cdot}5$ kg. per sq. mm. This compares with 34 for brass, 30 for copper, 60 for iron, and 80 for steel. It is probable that the highest values for the tensile strength of the material (those over 100) are more nearly correct, but the interest of this measurement lies in the probability

TABLE 6

Weight in mg. per 10 cm.	*Area in cm.² × 10⁻⁴*	*Breaking-strain gm.*	*st kg./mm.²*	*Breaking-length km.*	*Density*	*Tensile strength kg./mm.² fibre-substance*
0·40	1·53	390	25·5	78·0	0·26	147
0·52	1·08	290	26·9	55·8	0·35	83
0·94	2·02	370	18·8	40·4	0·46	60
1·02	2·17	370	16·6	35·3	0·47	53
1·40	2·55	460	18·0	32·9	0·55	49
1·52	1·99	620	31·2	40·8	0·54	61
1.70	2·19	370	17·5	22·4	0·78	33
1·86	2·85	990	34·7	53·2	0·65	80
2·00	4·28	660	15·4	33·0	0·41	49
2·02	1·82	760	41·7	37·6	1·11	56
2·16	2·49	1,130	45·4	52·3	0·87	78
2·24	2·57	890	34·6	39·7	0·87	60
2·26	2·37	850	45·9	37·6	0·95	57
2·44	3·48	960	21·6	39·3	0·70	59
2·54	2·67	1,200	44·9	47·3	0·95	70
2·56	3·08	1,510	49·0	59·0	0·83	88
2·62	1·82	540	29·7	20·6	1·44	31
2·64	4·39	790	18·0	29·9	0·60	45
2·64	2·77	700	25·3	26·5	0·95	40
2·68	2·72	660	24·7	24·6	0·99	37
2·76	3·75	1,090	29·1	39·5	0·74	59
2·78	4·06	2,950	72·7	106·2	0·68	158
2·80	3·35	1,260	37·6	45·0	0·84	67
2·98	4·41	1,190	27·0	39·9	0·68	60
3·28	3·32	560	17·3	17·6	1·01	26
3·40	3·96	860	21·6	25·3	0·85	38
3·40	2·97	1,510	50·8	44·4	1·14	67
3·70	4·36	890	20·4	24·1	0·85	36
4·22	6·96	1,260	18·1	29·9	0·61	45
4·34	6·15	1,750	28·5	40·3	0·71	60
4·40	4·66	1,220	26·2	27·7	0·94	42
4·40	7·13	1,190	16·7	27·0	0·62	40
4·42	6·56	2,990	45·6	67·4	0·65	102
4·44	5·87	1,200	20·4	27·0	0·76	40
4·46	6·45	1,160	18·0	26·0	0·69	39
4·50	7·02	1,100	14·1	24·2	0·58	40
4·52	8·17	1,890	23·1	41·8	0·55	62
4·58	7·92	890	11·2	19·4	0·58	29
4·82	5·52	1,560	28·3	32·4	0·87	49
5·00	7·16	1,500	21·0	30·0	0·70	45
5·66	6·78	1,280	18·9	22·6	0·83	34
5·86	8·39	2,180	26·0	37·2	0·70	56
6·06	6·30	880	24·0	14·5	0·96	22
7·34	9·98	1,620	16·2	22·0	0·74	33
Averages						
3·24	4·38	1,102	27·5			
Calculated from above averages				34·0	0·75	51

that the value recorded, about 55, would normally be attained in actual practice.

Relation between the age of plant and strength, length, and amount of fibre produced by a leaf.—A mature plant of sisal was chosen, all the leaves being present, from the early 'sand leaves', produced too early in the life of the plant to be worth while cutting commercially, to the very young leaves, not yet unfolded from the central bud. Leaves were cut in spiral fashion round the plant, beginning at the bottom, and continuing until a leaf of the central bud was reached. Sixteen leaves were cut, and the number of fibres per leaf of these is given in Table 4, Pt. I (this *J.*, 1936, 5, 84). Alternate leaves were decorticated by hand and the fibres from each leaf randomized and broken in the usual manner. The results are given in Table 7.

TABLE 7. *Mechanical Qualities of Fibre Produced at Different Times in the Life of the Plant*

Position of leaf on plant	*n*	*F*	*s*	*L*
2	455	4·03	1,621	40·2
4	899	3·44	1,581	46·4
6	967	3·17	1,680	53·0
8	910	3·91	1,701	43·5
10	927	3·64	1,833	50·4
12	934	3·97	1,784	45·1
14	836	3·75	2,126	56·5
16	535	4·37	1,979	45·3

In Table 8 are given the frequency-distributions of the breaking-strains of the fibres from each leaf. For convenience they have been classified in 400-gm. intervals, and Fig. 3 (p. 105) shows the general tendency for the higher-strength classes to increase in frequency at the expense of the lower-strength classes as the leaves towards the bud are approached. It is plotted in 800-gm. class-intervals for clarity.

TABLE 8. *Frequency-distributions of Breaking-strains of Fibres from Leaves Produced at Different Times in the Life of the Plant*

Class central points	*Percentage Frequency*							
	Leaf no. 2	*Leaf no. 4*	*Leaf no. 6*	*Leaf no. 8*	*Leaf no. 10*	*Leaf no. 12*	*Leaf no. 14*	*Leaf no. 16*
200	4·4	4·4	5·6	6·8	4·2	4·1	3·2	5·2
600	9·0	13·5	10·9	7·8	6·9	7·0	5·5	5·2
1,000	11·4	15·1	16·3	15·7	14·2	13·8	7·5	7·5
1,400	12·7	19·5	13·2	16·4	16·7	16·2	11·5	11·6
1,800	19·4	22·2	16·3	16·0	15·0	18·9	15·8	15·5
2,200	16·7	11·3	15·8	18·5	14·4	18·0	16·7	17·2
2,600	9·7	8·1	10·5	11·1	13·2	11·5	17·1	17·9
3,000	4·2	4·9	7·5	5·0	9·9	7·3	13·2	13·8
3,400	0·9	1·9	2·7	2·0	4·1	3·7	7·5	7·3
3,800	..	..	0·3	1·7	1·3	0·5	2·3	0·9

The data embodied in Tables 9 and 10 are due to Mr. Lock, of the Tanganyika Agricultural Department, to whom I am indebted for permission to publish them.

Six leaves were cut from a mature sisal plant, covering the whole leaf-range, with the exception of the earliest sand-leaves (my No. 2), and the leaves of the central bud (my No. 16). Number 1 is the oldest leaf, i.e. that formed when the plant was young, and No. 6 is a leaf adjacent to the bud, i.e. one formed later in the life of the plant. The leaves were decorticated separately by hand, and the fibre from each was classified in length-groups and weighed. The results are given in Table 9.

TABLE 9. *Distribution of Fibre by Length in Leaves of One Plant of* Agave sisalana

Leaf number	*Class central points for fibre-length (cm.)*											
	5	*15*	*25*	*35*	*45*	*55*	*65*	*75*	*85*	*95*	*105*	*Total*
1	0·8	1·3	1·2	1·4	1·5	2·0	2·7	2·0	3·3	6·1	5·1	27·4
2	0·3	0·6	1·0	1·5	1·8	2·2	2·3	4·5	3·9	7·8	6·2	32·1
3	0·5	0·7	0·9	1·2	1·2	1·4	2·3	3·9	3·9	5·8	6·4	28·3
4	0·5	0·8	1·1	1·3	1·2	1·7	2·2	1·4	3·2	5·4	10·9	29·7
5	0·7	1·1	1·5	1·4	1·9	1·5	1·4	3·3	3·0	4·1	10·0	29·9
6	0·6	1·0	1·0	1·4	1·7	2·1	2·0	3·1	1·9	4·4	12·2	31·4

The figures represent the weight, in grams, of air-dried fibre, of the length-class indicated, from each leaf.

TABLE 10. *Distribution of Fibre by Number in the Leaves of One Plant of* Agave sisalana

Leaf number	*Class central points for fibre-length (cm.)*											
	5	*15*	*25*	*35*	*45*	*55*	*65*	*75*	*85*	*95*	*105*	*Total*
1	176	177	118	105	91	97	110	73	105	165	94	1,301
2	83	89	94	96	98	105	113	126	128	149	100	1,181
3	200	126	135	121	95	90	120	135	128	138	112	1,400
4	128	118	120	100	71	84	92	52	104	144	197	1,210
5	148	146	140	106	113	80	62	114	85	112	198	1,304
6	129	138	99	101	101	86	70	98	61	110	215	1,208

The figures represent the number of fibres in each length-class as indicated, in each leaf.

From the combined data the following conclusions can be drawn:

1. The average strength of the fibres from a leaf of sisal increases with the age of the plant at the time the leaf was formed.

2. The fineness of the fibre decreases slightly with the age of the plant, except the earliest sand-leaves, which have a relatively coarse fibre.

3. The increase in strength is due to an increase in frequency of the strong fibres and a concomitant decrease in the weak fibres (see Fig. 3). There is also a tendency for the intrinsic strength of the fibre to increase.

4. The number of the fibres per leaf, and the weight of the fibre per leaf remain relatively constant. There will be little variation in the amount of fibre extractable by a decorticator from leaves produced at different times, since

5. There is an increase in the proportion of the longer fibres in leaf produced late in the life of the plant, but this is accompanied by a reduction in the moderately long fibres, and not in the short ones.

6. The evidence is against the prevailing opinion that the leaf of sisal matures somewhat after it has unfolded from the bud. If there were any

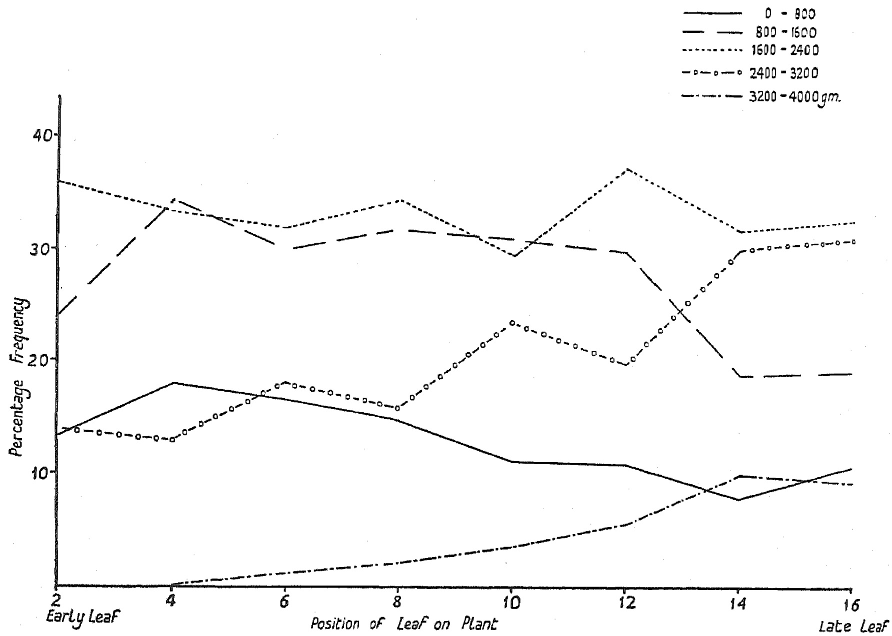

FIG. 3. Percentage frequencies of breaking-strains of fibres from *Agave sisalana* leaves of different ages.

maturation-period, after unfolding, the figures for the qualities concerned should show a maximum or minimum at some intermediate position. There is a short maturation-period for leaf-length, and this is shown clearly enough, but neither Mr. Lock's figures, nor mine, show a maximum for any other fibre-quality (with the exception of my No. 16, which is a leaf taken from inside the bud, where maturation indubitably occurs). It is therefore probable that the length-distribution, the number, and the strength of the fibres of each leaf, together with their total weight, do not alter appreciably once the leaf has unfolded from the central bud.

These results have some practical application. Sisal plants are cut with varying degrees of severity on estates, but it is often stated that only the leaves below an angle of about 45° to the vertical should be cut, since those above this level are younger, their fibre has not matured, and is therefore inferior. It is also stated that the quantity of fibre in these

younger leaves is less than it would be if they were left longer on the plant.

All the evidence goes to show that this is not so. The strength, number, quantity, and length of the fibres produced by an estate will not be adversely affected even if cutting is carried out up to the central bud. This is not to say that such action is desirable. There is bound to be an optimum severity of cutting on other grounds, possibly connected with the subsequent rate of growth of the new leaves.

On the evidence put forward here, it would appear that the later cuts of commercial sisal should be stronger, very slightly coarser, and should contain a somewhat higher proportion of the longest fibres. This may be so, but in the data given previously for strength and fineness of commercial sisal from estates, the variation is too small to be detectable, being masked by the large variation from area to area.

Elasticity and ductility of sisal fibres.—Cordage, for which agave fibres are most widely used, is by its very nature subjected to tensile strains, and hence the intrinsic properties of fibres when subjected to strains less than the breaking-strain are obviously of fundamental interest.

The results here reported are of a general nature. No method has yet been developed for the comparison of the elastic properties of samples. Work is continuing, and it is hoped to publish more exhaustive data in due course.

The apparatus used is illustrated diagrammatically in Fig. 4. It consists of a stout wooden framework carrying a balanced lever, the short arm of which carries a grip for the fibre under test, the other end of the fibre being held in a similar grip 18 cm. below. The longer arm contains a threaded rod, on which travels a nut carrying a weight. The rod is rotated by an electric motor, through a chain of reduction-gears and a reversible gear-box. The connexion to the rod is by gear, a gear-wheel on a short fixed axle transmitting power to a similar wheel on the threaded rod. The knife-edges forming the points of balance for the lever are placed so that the line joining them is parallel to the axles of both the wheels and passes through the point where the wheels touch each other. Thus no moment tending to turn the lever is transmitted.

As the rod rotates, the weight moves along it; thus a steadily increasing or diminishing load is applied to the fibre. The rate of loading varies over a wide range, from 1,000 gm. per week to 1,000 gm. per 5 minutes being obtainable by varying the speed of rotation of the rod, whilst 'instantaneous' loading is obtained by hanging a weight on a hook attached to the end of the lever-arm.

The recording of the extension is automatic, and is carried out as follows: An extension arm, 6 ft. long, is attached to the longer arm of the lever. Mica vanes attached to this and immersed in oil provide sufficient damping to offset the effects of vibration. A light pen, drawn from quill tubing, just touches the paper on a recording drum. The latter is driven through appropriate gearing by the same driving-gear as the moving weight. Hence the reversal of the drum is automatic, and any variation

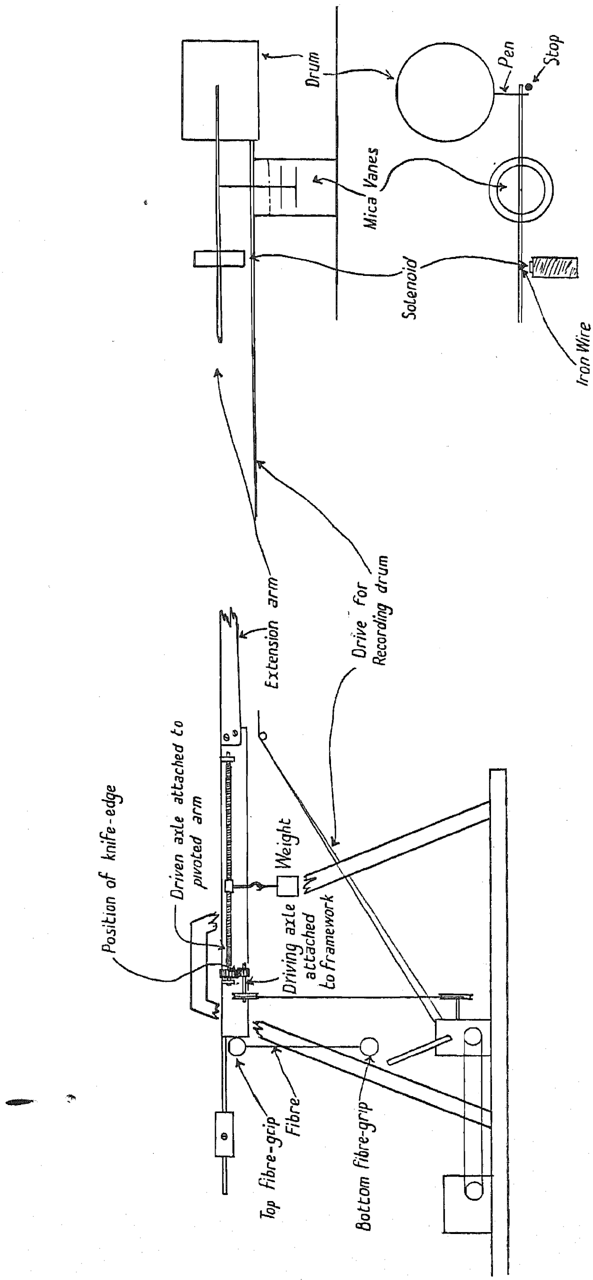

FIG. 4. Apparatus used for measuring elasticity and ductility. The method of recording is shown in plan and elevation.

in the rate of loading due to irregularities in the supply of electric current to the motor is accompanied by a concomitant variation in the speed of rotation of the drum.

The effect of friction between the pen and the paper, always troublesome when a long recording-lever is used, is overcome in the following manner, and is shown both in plan and elevation in Fig. 4. To the end of the lever is attached a vertical iron wire, arranged to be in the field of an electro-magnet. This holds the pen off the drum while the circuit is closed. At intervals, contact is broken by means of an interval-timing clock, the pen falls against the paper for a few seconds, and makes a dot. During its travel from the paper to the magnet and its return, the lever is free from all friction at the end. An additional advantage of this method of recording is that, by altering the time-intervals, and hence the spacing of the dots, any curve can be automatically isolated from others. The spacing of the dots is always altered for a 'recovery curve'.

Around the fibre is a long narrow metal box (not shown in the diagram) through which conditioned air can be passed during a test, since humidity variations alter considerably the elasticity of the fibre. The results quoted later are all taken at one humidity, 75 per cent.

Rate of extension under constant load.—Fibres were arranged between the grips and a load of 400 gm. applied by hanging a weight to the end of the longer arm of the balance. The time-extension curve was followed. The weight produced an 'immediate' extension varying, of course, with the diameter of the fibre, this extension being followed by a much slower one. This slow extension takes two or three days to complete, and eventually the fibre remains at a constant length. On the removal of the weight an 'immediate' recovery takes place, followed in turn by a slow contraction. The total contraction is about half the total extension.

When a fibre, already having been subjected to extension and recovery as described above, is reloaded, the bottom part of the above curve is retraced exactly. Upon unloading the fibre, the upper portion is retraced. Fig. 5 shows the curve of extension and recovery with time. The hysteresis loop of a stretched agave fibre is retraced apparently indefinitely.

Thus sisal is ductile, since it can be permanently stretched by loading. It is also, when already stretched, perfectly elastic, provided that the strain producing the second extension is not greater than that producing the original increase in length. Hooke's law is followed exactly, in that equal increments in strain produce equal increments of elongation, and the elongation is not permanent.

Young's modulus for the fibre-material of sisal was determined for a sample at a relative humidity of 75 per cent. as follows:

Individual fibres were weighed, stretched on the machine under a uniform weight, and the first 'immediate' extension measured. Then, assuming the density of the fibre-material to be 1·5, m to be the mass in gm. of a 10-cm. length, A the cross-sectional area of the fibre-substance, P the force applied in dynes, and L and $L+1$ the original and stretched length of the sample, then

$$m = 15A$$

Young's modulus = stress ÷ strain

$$= 15\,PL \div ml.$$

For the sample under test

$$n \text{ is } 45,\ \bar{x} \text{ is } 2{\cdot}647,\ s^2 \text{ is } 0{\cdot}1404$$

Young's modulus is $2{\cdot}647 \pm 0{\cdot}057 \times 10^{11}$ dynes/cm.^{2} for the conditions specified. For higher relative humidities the result will be smaller, and conversely, the value of Young's modulus will increase with increasing dryness of the fibre.

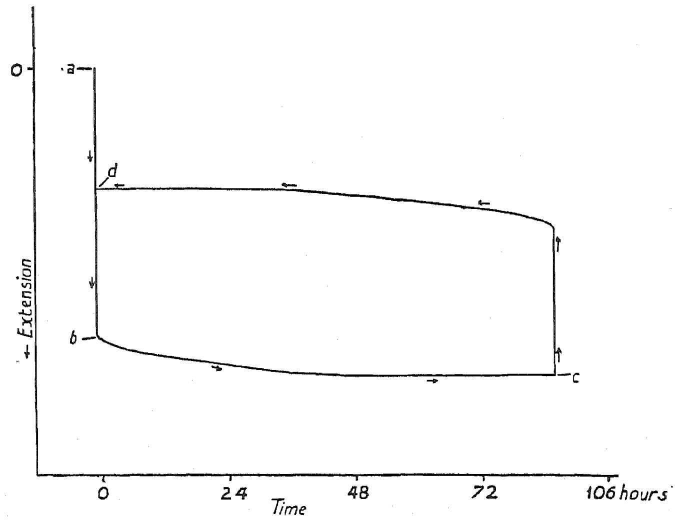

FIG. 5. Extension and recovery of sisal fibre under constant load.

at *a* load applied.
abc extension curve.
at *c* load removed.
cd recovery curve.
at *d* load applied.
dbc extension curve, and so on.
dbc is hysteresis loop.
ad permanent extension.

Rate of extension under increasing load.—For this determination a fibre is placed in the test-machine and loading applied gradually by causing the weight to move out along its arm. The extension produced at any moment is recorded on the drum. After an appropriate interval the movement of both the weight and the drum is reversed. The pen now traces the recovery curve. Fig. 6 shows the type of curve produced with low rates of loading. The stress-strain curve for the first loading is a straight line. After the first loading, the stress-strain curve for both loading and unloading follows the second straight line. Over this part of the curve the fibre is perfectly elastic.

The linearity of the relation between stress and strain is unusual in fibres. Other fibres appear to give curves either concave or convex in form; also they do not seem ever to reach the condition attained by sisal after a single loading, viz. that the length of the fibre depends only on the

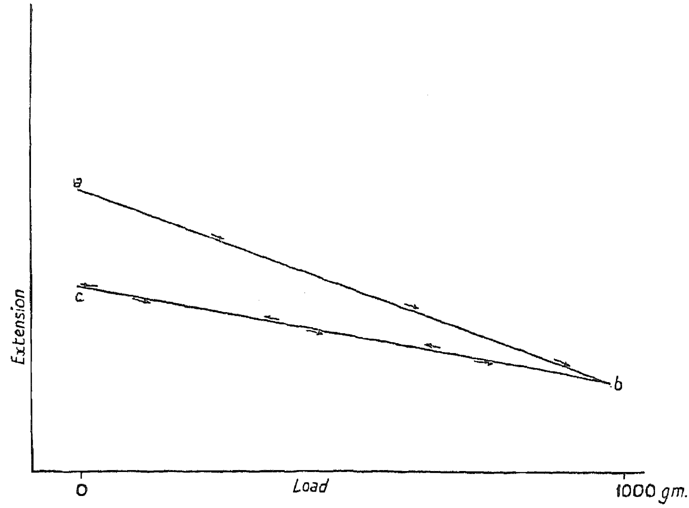

FIG. 6. Relation between load and extension of sisal fibre. Rate of loading, 1 kg. per 50 hours.

at *a* loading starts.
ab extension curve.

at *b* unloading starts.
bc recovery curve.

at *c* reloading starts.
cb extension curve, and so on.

ac is permanent extension.

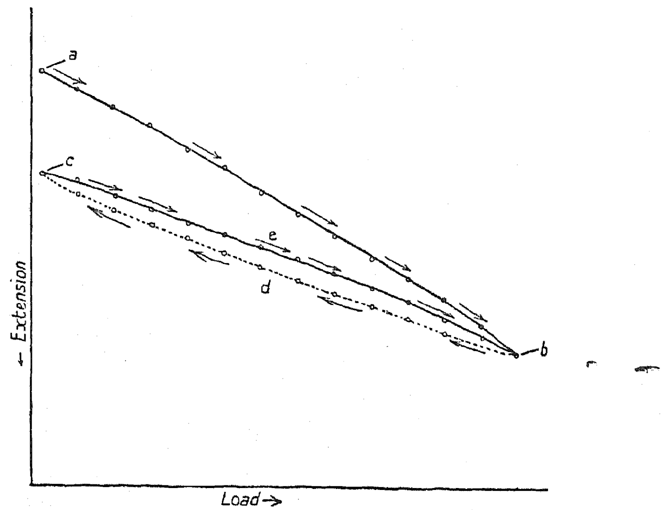

FIG. 7. Extension curve of sisal fibre for rapid rate of loading, 200 gm. per minute.

at *a* loading started.
ab extension curve.

at *b* unloading started.
bdc recovery curve.

at *c* reloading started.
ceb extension curve, and so on.

stress applied, irrespective of whether the fibre is being unloaded or loaded.

When the increasing stress is continued until the fibre breaks, no departure from linearity is seen (with low rates of loading) right up to the breaking-point. The rate of loading has been reduced to 1 kg. per week, with no departure from linearity.

At higher rates of loading a hysteresis loop is formed on the recovery and reloading part of the curve. This is probably explicable on the grounds that, during unloading, the contraction of the fibre lags behind the load at any point, and, conversely, during reloading the extension shows a similar lag. The loop narrows with decreasing rate of loading, and finally forms a straight line. Fig. 7 illustrates the stress-strain curve for a rapid rate of loading.

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The Kenya, and the Tanganyika Sisal Growers' Associations have also been helpful in one way or another.

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THE ROOT-SYSTEM OF THE SUGAR-CANE

Pt. IV. ABSORPTION AND EXUDATION OF WATER AND MINERAL SUBSTANCES

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With Plate 5.

Absorption of Mineral Substances

Data concerning the absorption of mineral substances by sugar-cane roots were obtained as part of a more comprehensive investigation into the course of growth in a virgin, or plant crop of White Tanna (Bulletin No. 7, 1935, of this Station). Twenty-five root-systems were excavated at intervals through the growing-season, and the 'fresh' and 'dry' weights of the roots were ascertained. Concurrently, the chief mineral substances were determined (*a*) in the stems, leaves, and roots, and (*b*) in the dead leaves, rhizomes, &c. (grouped under the term 'Etceteras'); and their total amounts in the whole plant were calculated for each period, each value being the mean for 25 stools.

The relationship between quantitative root-growth and absorption of mineral substances has been followed from the time the young plants were established to the time of harvesting the crop. Data on the climatic conditions and the fresh and dry weights of roots per stool for the period of the experiment are given in Table 1.

Table 1

Month	*Rainfall (mm.)*	*No. of days on which rain fell*	*Accumulated 'day degrees'*[1]	*Fresh Wt. of roots per stool*	*Dry Wt. of roots per stool*	*Dry Matter per cent.*
March 1933	205·7	31	279	14·1	2·9	78·96
April ,,	101·8	25	264	45·7	6·2	84·93
May ,,	73·0	26	205	92·7	14·0	84·18
June ,,	66·7	25	147	152·2	25·2	93·46
July ,,	73·8	26	96	249·7	44·2	82·72
Aug. ,,	34·8	22	106	331·6	65·9	80·50
Sept. ,,	50·9	23	113	396·8	72·6	81·98
Oct. ,,	22·7	19	178	359·5	72·5	79·90
Nov. ,,	15·1	16	228	333·0	75·2	76·78
Dec. ,,	47·3	25	286	333·0	77·9	76·60
Jan. 1934	275·6	21	304	..	..	..
Feb. ,,	40·4	23	277	690·8	149·4	78·39
March ,,	59·1	30	297	..	..	..
April ,,	36·4	25	256	776·4	173·0	77·80
May ,,	170·2	30	213	..	..	..
June ,,	84·4	29	134	..	..	..
July ,,	46·0	28	94	715·2	155·9	77·82
Aug. ,,	56·8	24	83	..	..	..
Sept. ,,	56·6	25	98	..	..	..
Oct. ,,	..	..	..	729·6	160·6	78·00

[1] The number of degrees over a basal number (15° C.) below which growth of sugar-cane is almost at a standstill.

The mean fresh and dry weights of roots per stool at intervals during the experiment are plotted in Fig. 1.

It will be seen that the weight of roots increased progressively from the time the observations began, through the cool months of June–August, until the start of the dry period (August–September), during which there was hardly any root-growth. The fresh weight of roots decreased significantly through lack of water in the dry soil, but even during this period the dry weight of the roots increased slowly. There was a remarkably close relationship between the soil moisture, calculated as per cent. of dry soil, and the water-content of the roots, expressed as a percentage of the fresh weight, the correlation coefficient being $+0{\cdot}878 \pm 0{\cdot}06$. The dry period of 1933–4 ended with torrential cyclonic rains on January 28–29, 1934, nearly 10 in. falling in two days. The remarkable increase in root-weights in the February harvest was due to this rain, there being a profusion of new white roots up to 9 in. long at the time the root-systems were excavated in February.

Almost every underground root-primordium germinated as a result of this rain, and further increase in the weight of the root-system between February and April was due more to continued growth of the roots just formed than to initiation of new roots. By the end of April these roots appeared to have completed their growth, further changes in the weight of the root-system up to harvesting time in October being insignificant.

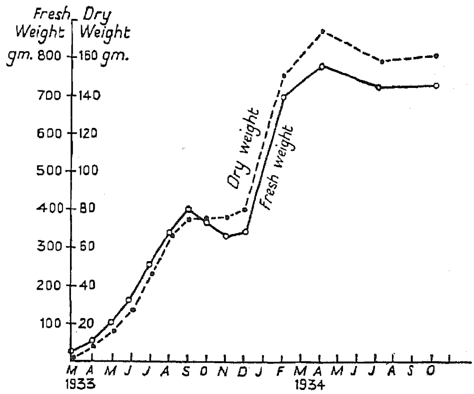

FIG. 1. Fresh and dry weights of roots at intervals through growing-season.

It thus appears that under any specific conditions of environment, the sugar-cane root-system tends to become constant, the properties of the mature root-systems depending largely upon the variety. The spatial distribution of the mature root-systems of the chief varietal types was described briefly in Part II of this series (this *J.*, 1936, 4, 208). There is little doubt that small changes occurred in the root-system during the period April–October 1934, since continuous decay and formation of absorbing rootlets were observed. These changes, however, are insufficient appreciably to affect the weight of the root-system.

The course of root-growth, depicted in Fig. 1, is held to be normal for Mauritius conditions, with the exception of the sudden increase between December and February. In a more normal year this increase would, undoubtedly, still have occurred, since the months January to April are the best for growth, being usually warm and moist; but it would have been more gradual. The constancy of the root-system from April to the time of harvest in October is also explained by the fact that practically all the root-primordia had germinated, and in the absence of new shoot-formation no new roots could be formed.

Total nitrogen, calcium, potassium, and phosphate in the dry matter of leaves, stems, and roots were determined separately and in duplicate. From the known total dry weights of leaves, stems, and roots, the total quantities present in the stool were calculated. The analytical results are presented in Table 2.

TABLE 2

Month	*Total Nitrogen in stool (gm.)*		*Total Calcium (as Ca) in stool (gm.)*		*Total Potassium (as K) in stool (gm.)*		*Total Phosphate (as P_2O_5) in stool (gm.)*	
	Excluding Etceteras	*Including Etceteras*	*—Etc.*	*+Etc.*	*—Etc.*	*+Etc.*	*—Etc.*	*+Etc.*
1933								
March .	0·192	..	0·033	..	0·164	..	0·032	..
April .	1·047	..	0·171	..	0·809	..	0·229	..
May .	1·255	..	0·409	..	1·623	..	0·540	..
June .	2·966	..	0·932	..	3·500	..	0·909	..
July .	4·594	..	1·232	..	4·209	..	1·122	..
Aug. .	6·535	..	1·646	..	6·045	..	1·203	..
Sept. .	6·792	8·139	1·868	2·983	6·926	7·916	1·772	2·086
Oct. .	7·100	9·980	1·985	3·754	6·655	8·128	2·352	2·995
Nov. .	7·770	12·091	2·203	4·634	8·753	10·646	2·584	3·471
Dec. .	6·923	9·977	2·034	4·644	10·210	12·025	2·129	2·734
1934								
Feb. .	10·922	14·021	2·600	4·553	13·210	15·282	2·551	3·141
April .	13·656	17·288	5·834	9·480	16·320	19·301	3·352	3·892
July .	16·996	21·194	6·922	11·388	20·509	22·631	4·361	4·941
Oct. .	21·544	26·522	9·350	13·854	18·779	19·865	6·408	7·274

Nitrogen.—The total amounts of nitrogen per stool at intervals through the season are plotted in Fig. 2.

Absorption of nitrogen is seen to have been continuous, and from March to December 1933 to have been very closely correlated with the growth of the root-system. It appears that the absorption of nitrogen was limited by the absorbing capacity of the root-system: from March to August, by the limitations of the root-system itself; and from August to December by the dry conditions. Just as root-growth almost ceased during this period, so also was the absorption of nitrogen very low. Following the rains at the end of January 1934, and the formation of new roots, nitrogen was absorbed at a higher rate, although this increased rate was not commensurate with the increase in weight of the root-system. This is to be expected, as the absorbing surface of the roots must be increased by branching and copious root-hair formation before absorption at a vigorous rate is possible. The absorption of nitrogen continued at a more or less steady rate until the time of harvesting. The cessation of root-growth in April 1934 did not cause a corresponding cessation of nitrogen absorption, indicating that although the weight of the root-system remained fairly stationary, its efficiency was not impaired. Efficient absorption is maintained by the continuous generation of minute absorbing rootlets as the older ones cease to act. During the whole period, the roots absorbed nearly 27 grams of nitrogen, of which about 5 gm. were found in the dead leaves, rhizomes, &c.

Calcium.—The absorption of calcium from March to December, 1933, followed that of nitrogen fairly closely (Fig. 3), though the absolute amount absorbed was, of course, much less. In the dry months, August to December, absorption of calcium was also nearly at a standstill. One very interesting fact appears, namely, that the rate of absorption of calcium following the cyclonic rains of January 1934 did not show an immediate marked increase, as was the case with nitrogen; the increase was slight and only became very marked between February and April. The increase in rate of absorption of calcium thus showed a lag after the formation of new root-tissue. The same lag occurred in the formation of leaf-tissue, and as the calcium exists in much higher concentration in the leaves than in the other organs, it appears as if the absorption of

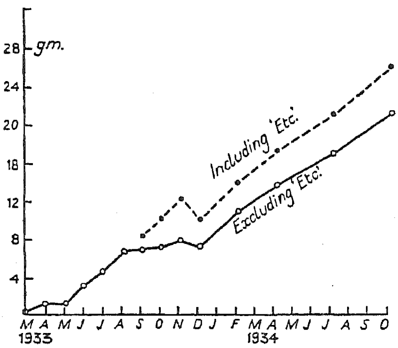

FIG. 2. Total nitrogen per stool at intervals through growing-season.

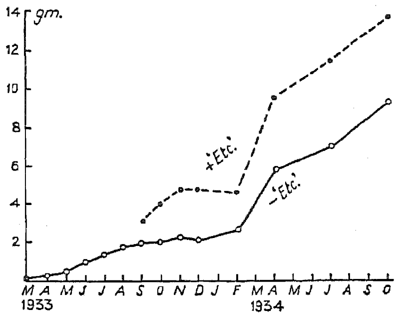

FIG. 3. Total calcium per stool at intervals through growing-season.

calcium is controlled to some degree by the leaves. The rate of intake of calcium decreased after April 1934, though it still remained quite appreciable up to the time of harvesting. It is doubtful whether the difference in rate during the periods April–July and July–October is significant. The roots absorbed a total of about 14 gm. of calcium, though much more was lost in dead leaves, &c., than in the case of nitrogen.

Potassium.—The curve of potassium-content per stool (Fig. 4) differs in several respects from the corresponding curves for nitrogen and calcium. Potassium was absorbed at a more or less steady rate until July 1934, when the rate declined and remained low until harvest time in October. The curve for potassium does not show the very marked flattening observed in the two previous curves during the period August–December, 1933. It is only the value in the October sample that is lower than would be expected. Absorption in the dry period (Oct.–Dec.) continued unabated, so that potassium still continues to be absorbed when most other elements are not. Potash is also the only element whose absorption declines at the end of the season. The decrease in potash-content per stool in the final sample taken in October, as compared with the previous one taken in July, is of doubtful significance, but the actual decrease in rate of accumulation of potash is certainly significant. The stool took up approximately 20 gm. of potash during

its complete growth, and of this very little was lost in the form of dead leaves, &c.

Phosphate.—The curve of phosphate-accumulation by the stool is shown in Fig. 5. As with the other elements, it followed root-growth in the first months; but the subsequent decline did not start in August 1933, as it did for nitrogen and calcium. Absorption continued vigorously until October, when there was a marked reduction, remaining very slow during the dry period. An appreciable increase in the rate of absorption followed the crop of new roots formed in January, and con-

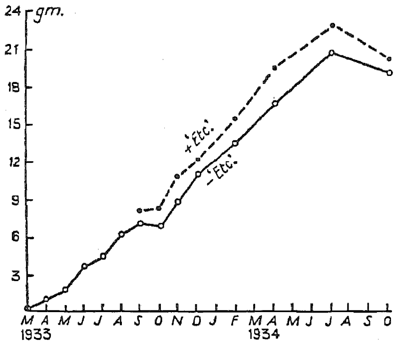

FIG. 4. Total potassium per stool at intervals through growing-season.

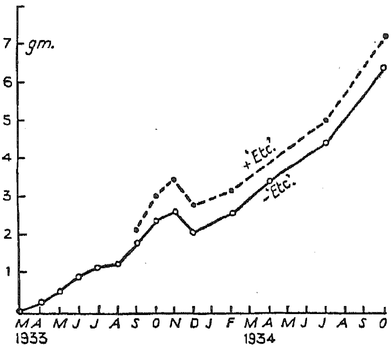

FIG. 5. Total phosphate per stool at intervals through growing-season.

tinued vigorously throughout the rest of the season. There was no falling off in the rate of absorption up to the time of harvesting in October 1934. On the other hand, no significance can be attached to the apparent slight increase in the rate of absorption during the period July–Oct. 1934, as compared with the period April–July. The amount of phosphate accumulated by the stool was of the same order as that of calcium, but there was comparatively little loss of phosphate in dead leaves, &c.

Total ash.—The ash from the stems and leaves was determined throughout the experiment, but as it was found impossible to eliminate traces of soil from the roots, and the ash-content of the roots varied so considerably, the determinations were discontinued on the roots. The values for ash-content thus refer to leaves plus stems, with and without the Etceteras.

	—Etc.	*+Etc.*		*—Etc.*	*+Etc.*
March	0·92	..	Oct.	45·76	91·75
April	4·37	..	Nov.	54·65	103·44
May	11·12	..	Dec.	44·62	111·31
June	16·46	..	Feb.	54·43	118·01
July	26·83	..	April	93·55	155·44
Aug.	43·60	..	July	125·35	220·21
Sept.	50·75	67·17	Oct.	149·41	250·41

The accumulation of total ash occurs continuously throughout the season, but there is a marked reduction in the rate of accumulation during the dry period, October to December (Fig. 6). There was no immediate increase in the total ash following the marked increase in the

weight of roots between December and February 1934. The increase, however, was very marked between February and April. Here again there is a lag between the formation of new roots and absorption of mineral substance. There was a definite falling off in the rate of absorption between July and October, showing that some other element present in the ash must have behaved in the same way as potash. This was probably silica, since about half the ash consists of it.

Summary of Data on the Accumulation of Mineral Substances

The absorption of mineral substances by the stool during the first eight or nine months of growth in this experiment was so closely corre-

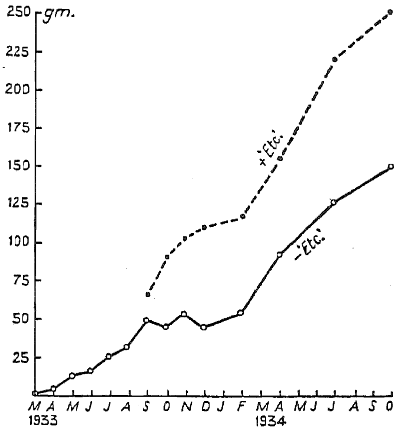

FIG. 6. Total ash-content per stool at intervals through growing-season.

lated with root-development that the root-system would appear to be the limiting factor in the absorption of mineral substances during this period. During the dry months, when the low moisture-content of the surface-soil makes absorption by the surface-roots almost impossible, there was very little absorption of mineral substances. Potassium was, however, accumulated at a vigorous rate even during this period. As a result of torrential rains in late January, absorption of nitrogen had greatly increased, the increase following almost directly on the protrusion of these new roots, since they were only 6 to 9 in. long when the February sample was taken. The increase in the absorption of other mineral substances did not follow directly on the protrusion of these roots, but occurred in the period February to April, when these roots had made further growth, and branched to a considerable extent. Later on, when the growth of the roots had ceased, absorption still occurred at a vigorous rate, showing that although the weight of the root-system did not increase, efficiency must have been maintained by the formation of new rootlets, which, though not affecting the weight of roots, must be of paramount importance in maintaining the absorbing function. In the mature stool it does not appear that the root-system limits the absorption of mineral substances.

Exudation of Water and Mineral Substances

It has been established that the phenomenon of root-exudation, i.e. the exudation of liquid from the cut stem, or from cut roots under the influence of root-pressure, is very active in sugar-cane, positive pressures being obtained almost throughout the year if conditions of moisture are favourable [1]. During the root-investigations, liquid was seen to drip from the ends of those roots which were severed near the stool, and the results presented here refer to the amount and chemical constitution of such liquid. To collect it, the stool was removed together with soil from a rectangular block, leaving undisturbed the portions of the roots outside this block. The soil was removed from the cut ends of the roots for a distance of 6 in., and the ends of the roots were washed and dried. Receptacles consisting of test-tubes with wire-holders coiled round them were fixed to receive the liquid, as shown in Plate 5. The exudation of liquid from cut roots is undoubtedly to be regarded as an abnormal phenomenon; nevertheless certain interesting information may be obtained from such studies. Thus Pierre and Pohlman [2], when investigating the relationship between the exuded sap of maize, sorghum, and sudan grass, and the composition of the soil solution in which they were grown, concluded that various soil-plant relationships could be elucidated by this means. They further concluded [3] that analysis of exuded sap presents possibilities in the study of phosphate-availability in soils. The results of phosphate-analysis of the exuded sap showed a good correlation with the response of maize plants to phosphatic manuring, and also with the water-soluble phosphoric acid and the available phosphoric acid, as determined by the Truog method. They also state that the method might be used to advantage in a study of the availability of various elements, particularly nitrogen and potassium.

Under the conditions of pronounced drought, when the experiments on exudation from White Tanna roots were performed, no liquid was exuded from the surface-roots in the first 8 in. of soil. Surface-roots between 8 in. and 1 ft. became slightly moist, but did not exude any appreciable amount of liquid. A moderate quantity was obtained from the buttress-roots to a depth of 3 ft. and the greatest quantity from the roots below this depth. A similar behaviour was observed in POJ.213 and Uba. Since the volume exuded is several times the volume of the root, the liquid must be absorbed from the soil. It is considered, therefore, that a root which exudes actively, must also be efficient in the normal function of absorption, for exudation must follow absorption at the distal end of the root. The converse, however, does not hold, viz. that if a root does not exude it is also incapable of absorbing, since the forces acting in the intact plant are entirely different from those acting in severed roots. Lack of available water might also prevent exudation.

In the variety POJ.213, copious watering was applied for two days before the stool was removed. Following this treatment, the surface-roots, in addition to buttress and deep roots, exuded vigorously. It appears, therefore, that the absence of exudation by the surface-roots was

due to the inadequacy of water in the surface-soil, and there is little doubt that in a drought, absorption by the surface-roots is also almost at a standstill. Absorption by the deeper roots, on the other hand, is continuous, since even in a drought the moisture-content of the deeper soil layers is adequate.

In the varieties Uba and M.104/30 (seedling of cross POJ.2878 × Uba Marot), where the root-system is very deeply seated, roots of the rope-system exuded an appreciable amount of liquid, even when severed at a depth of 15 ft. This liquid must, therefore, have been absorbed from depths greater than 15 ft. Since the subsoil is regarded as being much poorer in mineral nutrients than the surface soil, and since, during periods of drought, only the deeper roots are capable of absorbing to any extensive degree, it might be expected that the plant would suffer from mineral starvation, in addition to inadequate water-supply, under such conditions. This is supported by the evidence (pp. 115–16) that there is but little increase in the content of mineral substances in the stool during the dry months September to December. The analysis of a composite sample of exudate from the roots of White Tanna are given in Table 3.

TABLE 3

Substances (pH of sap 6·1)	*Amount in mg. per 100 c.c.*
Total dry matter	220·00
Total ash	125·00
Iron	Traces
Aluminium	Traces
Calcium (Ca)	9·00
Potassium (K)	14·20
Sodium (Na)	0·14
Magnesium (Mg)	5·06
Silica (SiO_2)	65·00
Manganese (Mn)	0·15
Ammonium (NH_4)	3·50
Nitrate (NO_3)	2·04
Phosphate (P_2O_5)	0·35
Chloride (Cl)	18·10
Sulphate (SO_4)	12·80
Sucrose	50·05

A noteworthy feature of the analysis is the very high proportion of silica in the ash. In the variety POJ.213, liquid was collected separately from each of the three root-types, after preliminary watering of the soil before removal of the stools. The liquid was also collected on three successive days, the exudate for each day being analysed separately. The results are given in Table 4.

It will be seen that the exudate from the three types of roots differs appreciably in composition, particularly in the content of organic matter, the amount of the latter associated with 100 mg. of ash being 76·9, 188·5, and 121·3 mg. for the surface, buttress, and deep roots respectively. The contents of potassium, magnesium, sulphate, and chloride are significantly higher in the exudate of the deep roots. Comparing the

TABLE 4

Substance	Surface-roots			Buttress-roots			Deep roots		
	1st day	2nd day	3rd day	1st day	2nd day	3rd day	1st day	2nd day	3rd day
Dry matter	203·2	..	..	312·00	..	..	273·60	..	..
Total ash	114·80	..	..	108·40	..	..	123·60	..	..
Calcium (as Ca)	3·50	3·50	3·56	3·56	3·50	3·56	3·46	4·21	3·56
Potassium (as K_2O)	10·40	11·62	14·36	14·36	11·21	14·30	19·71	14·78	17·47
Silica (as SiO_2)	70·00	46·80	40·80	56·00	46·00	40·50	71·20	49·00	51·00
Magnesium (as Mg)	1·57	2·18	2·05	..	..	..	3·89	4·36	3·75
Manganese (as Mn)	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Sulphate (as SO_4)	9·06	8·41	9·39	15·16	..	14·83	14·50	14·83	15·49
Chloride (as Cl)	13·31	14·38	15·44	11·00	14·56	16·33	12·78	16·15	17·40
Nitrate (as N)	1·28	0·60	0·58	0·90	..	0·58	0·65	0·55	0·45
Phosphate (as P_2O_5)	1·14	0·59	0·43	0·67	0·59	0·59	0·51	0·59	0·59

TABLE 5

Substance		No. of collection											
		1	2	3	4	5	6	7	8	9	10	11	12
Ca	S	3·28	3·11	3·91	3·44	3·52	3·36	3·36	3·82	3·64	4·16	4·54	3·68
	D	..	3·36	4·87	4·66	..	4·81	4·91	5·05	5·04	6·05	5·80	5·96
K_2O	S	20·05	20·84	19·72	17·93	13·00	11·43	12·32	13·89	10·09	11·20	11·21	..
	D	24·17	21·51	22·63	19·27	16·13	15·56	15·56	14·79	13·00	12·55	10·76	..
NH_3	S	3·00	5·10	3·74	3·91	1·36	..	..	..	..	..	..	..
	D	2·00	1·50	..	..	..	..	..	..	..	..	..	..
NO_3 as N	S	1·25	..	1·20	..	0·92	0·66	0·27	0·17	0·17	0·19	0·15	0·21
	D	0·36	..	0·36	..	0·32	0·18	0·12	0·08	0·09	0·10	0·09	0·12
P_2O_5	S	2·96	2·22	2·76	2·22	1·68	1·75	1·75	1·75	1·75	1·38	1·11	0·96
	D	1·11	0·48	0·84	0·84	0·75	0·66	0·66	0·57	0·39	0·25	0·20	0·84
SO_4	S	19·12	25·13	26·04	24·14	18·95	16·07	13·93	13·68	11·84	11·04	12·36	..
	D	..	..	..	..	..	..	18·46	16·81	11·54	15·86	10·14	..
Cl	S	19·30	8·70	8·17	8·52	8·88	8·75	10·30	12·43	14·50	16·56	21·65	..
	D	23·86	23·08	21·12	22·19	20·77	20·95	22·90	27·16	29·45	30·88	34·26	..

S = Surface-roots. D = Deep roots.

two varieties White Tanna and POJ.213, one of the most striking differences is the almost complete absence of manganese in the exudate of the latter, whereas fairly appreciable amounts of it were present in White Tanna.

Using the variety Uba, the analyses of exudate from surface-roots and from rope-systems, severed at a depth of 6 ft., were carried out.

The liquid was collected in one- or two-day samples for a period of 3 weeks. The results are given in Table 5.

The results, in the main, confirm those obtained with POJ.213; the exudate from the deep roots contains in general more calcium, potassium, chloride, and sulphate than does the exudate from the surface-roots, but that from the surface-roots contains more phosphate, nitrate, and ammonia. Nitrites also were present in much larger amounts in the exudate from surface-roots. Manganese was present in the exudate in similar concentration to that found in White Tanna. The presence of boron in minute traces was also established.

It is a remarkable fact that the thin roots of sugar-cane when severed, and left undisturbed in the soil, remain alive and functioning for at least one month. The changes in concentration of the mineral substances with time are rather complicated and difficult to interpret. In general, the behaviour of exudate from surface-roots and deep roots is similar. The comparison of curves for different substances, however, shows considerable differences (Fig. 7).

The greater quantity of certain substances in the exudate of deep roots does not, of necessity, imply greater absorption of these substances by the deep roots. During exudation, materials stored in the roots escape in the exudate, and it is possible that deep roots might store certain substances in greater amount. This possibility was tested by analysing roots of Uba from the first 8 in. of soil, and from a region between 3 ft. and 8 ft. in depth. The results are given in grams per 100 grams dry roots:

	% dry matter	*Ca*	K_2O	P_2O_5	SO_4	*Cl*
Surface-roots .	27·0	0·419	0·404	0·084	0·245	0·059
Deep roots .	28·5	0·134	0·195	0·044	0·151	0·028

Thus the concentration of all the substances investigated is higher in the surface-roots, so that the higher concentration of certain substances in the exudate of deep roots is not due to their being stored in greater amount and therefore lost to the exudate at a faster rate. It can be shown, moreover, that in the case of certain substances, the greater quantity in the exudate is due to a greater absorption by the deep roots. The results for chloride only are given here.

A sample of 30 deep roots gave on an average 300 c.c. of exudate per day for 15 days (and were still exuding after this time). The mean chloride-content of the exudate was 25 mg. per 100 c.c., and the quantity of chloride exuded was therefore 1,125 mg. The total chloride in samples of deep roots was on the average 0·028 per cent. of the dry roots.

Let us assume that each one of the 30 roots from which the exudate was collected is 20 ft. long (a maximum value, as many do not reach this length); there would therefore be 600 ft. of root. Let us also assume that 1 ft. of root gives 2 gm. of dry matter (this again is a maximum value, as repeated weighings gave the dry weight per foot as 1 to 1·5 gm.). The total dry-weight of the roots would therefore be 1,200 gm., which, with a chloride-content of 0·028 per cent. would give the total amount

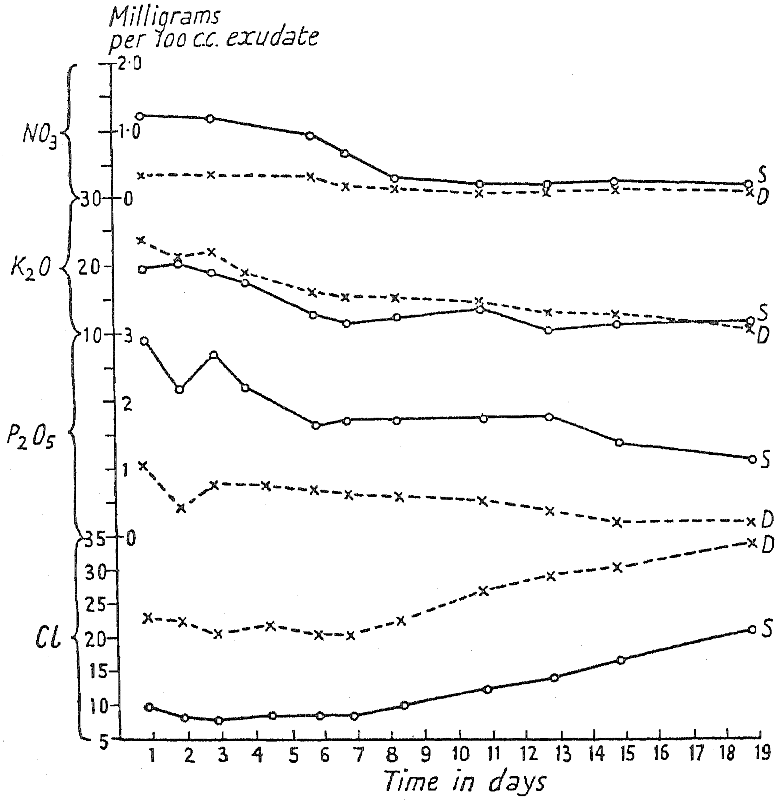

FIG. 7. Curves showing changes in content of various mineral substances in exudate.
S = Exudate of surface-roots.
D = Exudate of deep roots.

of chloride present as 312 mg. As has been stated, the total amount of chloride exuded was 1,125 mg., so that if all the chloride originally present was lost in the exudate, there is still an excess of 800 mg. to explain. There is, therefore, little doubt that this chloride has been absorbed by the deep roots, and that deep roots absorb more chloride than the superficial roots. An approximate evaluation of a similar nature points to the conclusion that potash was absorbed by surface-roots and deep roots during the period of the experiment, though it is difficult to state whether the deep roots absorbed more potash than the superficial roots.

It is of interest to compare the greater amount of potash in the exudate

from deep roots with the accumulation of potash by the stool during its growing-period (pp. 115–16).

Potash was accumulated in considerable quantities even during the dry months, when very little of the other mineral substances were absorbed. As only the deeper roots are able to function during drought, it appears that the deep roots must supply the stool with a considerable quantity of potash. This is confirmed by the fact that although the surface-soil in this plot contained nearly three times the quantity of potash contained in the subsoil at a depth of 6 ft., the amount in the subsoil was quite appreciable (29 mg. K_2O per 100 gm. dry soil). The greater absorption of chloride by the deep roots is explained by the fact that the subsoil contained 14·2 mg. chloride, whereas the surface-soil contained only 4·6 mg. per 100 gm. dry soil.

Discussion

It appears that all sugar-cane roots, if they are alive and bear root-hairs, are capable of absorbing both water and mineral salts. The distinction between feeder-roots and anchoring roots in sugar-cane is not strictly accurate, since all living roots are capable of absorption. It is true that superficial roots contribute by far the greatest quantity of important mineral substances to the growing stool, but that is mainly because they are situated in the surface-soil wherein these substances are mostly located. When minerals also occur in considerable quantities in the subsoil, as do chlorides and, to some extent, sulphates in Mauritius, they are vigorously absorbed by the deep roots. The deep roots at all times play an important part in the supply of water to the stool. The slowing down of absorption by the surface-roots, under dry conditions, and consequent dependence of the stool on the deep roots for its water-supply, indicate that a deficiency of certain mineral substances, particularly nitrogen and phosphate, may occur under dry conditions.

It appears reasonable to suggest that application of mineral substances for the deep roots might always be expected to be beneficial, and more particularly under dry conditions. There are, of course, practical difficulties in the way of deep fertilizer applications, but generous applications of fertilizers worked into the bottom of the hole before planting is a step in this direction. This does not imply that the complete dressing should be applied at a depth; the additional broadcasting of fertilizer for the benefit of the superficial roots was suggested in a previous paper (this *J.*, 1936, **4**, 330–1).

The general course of absorption of mineral substances indicates that there are two periods of active accumulation under normal Mauritius conditions, viz, (1) from the time the canes are established up to the initiation of the dry period, and (2) from the 'initiation' of the second 'grande saison' until the canes are almost mature. It is considered that availability of mineral elements in sufficient quantity is of paramount importance for the first period, and of lesser importance for the second period.

Investigations of the absorbing capacity of roots must take due con-

sideration of the environmental conditions, not only because the formation of absorbing tissue is dependent on climatic and soil factors, particularly soil moisture, but because a root, potentially well-equipped for absorption, might be rendered completely inactive for the time being by inadequacy of soil moisture or of mineral elements. After a period of prolonged drought, it takes two or three days of rain or irrigation before the superficial roots are capable of absorbing. This is undoubtedly due to the mortality of root-hairs under conditions of drought, and the necessity for a regeneration of absorbing tissue.

Summary

1. The course of root-growth in a virgin, or plant crop, of sugar-cane has been described. By making concurrent determinations of the total quantity of the most important mineral substances in the stool, it was possible to investigate the relationship between absorption of mineral substances and root-development. Information on the influence of dry conditions on the functional activities of the roots was also obtained.

2. The results of an investigation of the exudation of water and mineral substances by severed sugar-cane roots are given. It is shown how studies of root exudation, although an abnormal phenomenon, may shed light on problems associated with the intake of water and mineral substances by the different types of sugar-cane roots.

3. The bearing of the results on certain aspects of the practical agriculture of sugar-cane are briefly discussed.

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Collecting exudate from cut roots

AGRICULTURAL EDUCATION IN THE COLONIAL EMPIRE

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AGRICULTURE is the main industry of the Colonial Empire, and during the past thirty years considerable attention has been given to the subject of agricultural education. Numerous experiments have been made, and as a result a reasonably comprehensive system of agricultural education is being gradually evolved. It must, however, be recognized at the outset that no single method of approach can be made universally applicable, as the circumstances in the several dependencies vary so greatly.

Considerable differences in the soils and climatic conditions exist, and the circumstances of the peoples themselves vary markedly. In some dependencies, estate or plantation agriculture has been developed with the aid of outside capital or by local enterprise. In others smallholdings are the rule, and the economic prosperity is built up on the occupations of peasants, whose industry may be directed towards the production of food crops for subsistence or a variety of crops for export. In some dependencies, also, export crops figure largely in the agriculture and there are large imports of foodstuffs, whilst in others the cultivation of food crops is the main occupation and exports consist of the surplus supplies not required for local consumption. The production of crops for export has received, however, a great stimulus during the past twenty years, but it is only necessary to compare Ceylon, with its important estate-industries of tea, rubber, and coco-nuts with, say, the Gold Coast or Uganda, with their cacao and cotton industries based on small producers, to appreciate the great differences in the circumstances which prevail. In Ceylon, holdings may extend to hundreds or even thousands of acres, whilst in the Gold Coast or Uganda the average cultivations are not greater than 4–5 acres in extent. On the other hand, there are in Ceylon or Malaya vast numbers of smallholdings mingled with the estates, and in certain districts of these dependencies the main agricultural industry is based on smallholdings which grow rice or other foodstuffs.

Some territories also are largely dependent upon single crops for their prosperity, whilst in others there is a wide variation of crops under cultivation.

Social conditions also differ widely, and whilst in some considerable advances have been made along the paths of Western civilization, in others the ancient order of social customs is maintained tenaciously. Attempts are being made to develop along the older paths based upon the indigenous laws and customs, and to introduce modifications only where these are rendered necessary by the requirements of the modern world.

With such variations in agricultural conditions and social customs, it is apparent that important differences will always exist, and the systems

of education must be devised to fit in with the actual requirements of the territory concerned. In no sphere is the recognition of the indigenous methods more important than in agriculture, and no sound development is to be expected which is not built upon the practices that have been found by experience over the years to suit the soil and climatic conditions of the territory or even the district concerned. Agricultural education must, therefore, be designed to meet the special circumstances, and to fit in with the requirements of the people in question. The wholesale translation of Western methods of agricultural education is not practicable, and modifications in methods must be made from territory to territory.

Recently a comprehensive survey of vocational agricultural education in the Colonial Empire has been undertaken by the Colonial Advisory Council of Agriculture and Animal Health, and has been published as Colonial No. 124.

Agriculture in Elementary Education

The above-mentioned survey does not include reference to work in the elementary schools. It is, however, generally recognized that a close relationship should exist between the teaching in the elementary schools and the lives and occupations of the people. As has been stated earlier, agriculture is the staple industry of the peoples of the Colonial Empire. It is, therefore, not surprising that much attention has been given in recent years to the creation of an agricultural bias in elementary education. It is accepted that the elementary village school cannot aim at producing trained agriculturists, but it is recognized to be important that an intelligent interest should be awakened in the school in the processes of nature and the agricultural surroundings of the rural child. Nature study and school garden-work are gradually becoming important parts of elementary education in most dependencies, and it is being found that more and more agricultural topics can with advantage be introduced into the school curricula.

The rural child starts with considerable advantages over the urban child so far as nature study is concerned. It has a background of local knowledge, and its powers of observation are generally keen. Interest in nature knowledge is quickly awakened and work in the school garden, if it is well done and carefully supervised, is appreciated. In all elementary rural schools, therefore, attempts are being made to illustrate lessons with agricultural topics and to draw upon local knowledge. In certain circumstances the school garden has proved its value and its use is being gradually extended. It provides illustrations from which useful lessons can be drawn, and a means for manual training in work which the rural child can comprehend.

It is usual to find that the school garden is mainly concerned with the cultivation of food crops and flowers from which lessons in the school can readily be given, but it has been found that many simple improvements of agricultural methods can be introduced through the medium of the school garden, and that useful lessons in seed-selection, cultivation methods, and manuring can be provided. New food crops have been

introduced to districts through these gardens, and trials with economic crops are becoming more and more common. There is, in fact, a general tendency at present for school gardens to extend into small school farms on which economic crops and fruit trees are grown, and to which poultry-keeping and bee-keeping are added. This extension of the work of school gardens into agricultural occupations necessitates an increasing collaboration between the educational and agricultural authorities, and when this has been effected successful results have been achieved.

A school garden or a school farm to be effective must be well run and maintained in a condition which is a credit to the neighbourhood. It is unlikely to produce satisfactory results unless it is better run than the surrounding smallholdings, and unless it is recognized that its work is not vocational but designed to help the children of the school to appreciate that numerous interests can be found in nature and their agricultural occupations which help to provide a satisfying life in rural surroundings.

For school garden-work to be effective it has been amply demonstrated that success is dependent upon the personality and training of the teacher. If he is keen and has been well instructed as to the role which a school garden or farm can play in the work of the school, good results are obtained. If not, little is achieved. Importance is consequently attached to the training of the teachers and to their being provided with an elementary knowledge of agriculture. Most training courses for teachers now provide courses in agriculture in their curricula, and in many dependencies the provision of adequate training courses for teachers is entrusted to the Departments of Agriculture. It has also become recognized that teachers in rural schools should not be left isolated, but that provision should be made for periodic supervision of the work in the schools and for refresher courses for the teachers. The work in school gardens is often assisted through visits from agricultural officers, and not infrequently arrangements are made for a certain degree of supervision to be exercised by such officers. In any system of dual control difficulties arise from time to time, but in many dependencies satisfactory working arrangements have been aimed at between the educational and agricultural departments, and frequent conferences are arranged to discuss progress.

The provision of school gardens or school farms has so far been mainly in connexion with boys' schools, but in Ceylon and certain other dependencies very useful nature study and work in school gardens are being undertaken at girls' schools. The importance of the provision for school garden-work at girls' schools is not yet fully recognized. In many dependencies, particularly in Africa, the women play an important part in the agriculture of the community. Circumstances vary with the different tribes, but in many the women assume a considerable responsibility in the production of the food for the family or the group. The men, it is true, are required to perform the heavy work of clearing the land and preparing the soil for planting, but in many cases on the women falls the greater share of the work in connexion with the actual planting and the general cultivation. In some cases certain crops are grown solely by the women and they are their sole property. The women

of Africa, in fact, play a most important part in the production of food, and it is, therefore, essential that in any provision for female education consideration should be given to the introduction, whenever practicable, of instruction in nature study and school garden-work.

Agriculture in Middle Schools

Attempts are being made to introduce agricultural sides to middle and secondary schools. So far only little development in this direction has taken place. At Achimota in the Gold Coast an agricultural side of the school has been developed, and is shortly to be extended. In Nigeria school farms have been attached to certain middle schools with very promising results, whilst in Cyprus rural middle schools with an agricultural bias are about to be established. In Jamaica, also, a scheme for rural continuation schools has recently been started with the object of providing for a continuation of elementary education in schools which provide a definite vocational training in agriculture and in such handicrafts as may be required by smallholders on their farms.

Vocational Agricultural Education

It is not intended, however, to elaborate the position in regard to the part which agriculture is beginning to play in elementary education or in the secondary schools, but rather to review the position at the present time in regard to the provision made for vocational agricultural training. As has been previously stated, this matter has been the subject of a comprehensive survey which has recently been published. From this it can be seen that progress is being made along different lines in the several dependencies. Briefly the position at present is as follows:

In the *West African Dependencies* provision is made in Nigeria for the training of assistants for the services of the Department of Agriculture and the Native Administrations at two agricultural schools, where courses of two years' duration are provided. In the Gold Coast, the training of assistants for the Agricultural, Veterinary, and Forestry Departments is also provided at the Kumasi Training Centre. At Achimota, also, an agricultural course is available for the sons of farmers, whilst in Sierra Leone similar provision is made at two schools, and in Nigeria at certain farm centres. The training of teachers in agriculture is also provided for at Achimota in the Gold Coast, and in Nigeria at certain experiment stations and school farms. In Nigeria these courses for teachers are of only short duration, but a scheme for the fuller training of teachers in agricultural subjects has recently been approved, and courses of one year's duration will be provided at selected centres. There also exists in Nigeria a special system of training in mixed farming and animal husbandry at farm centres, and considerable progress is being made.

In the *East African Dependencies* greater attention has perhaps been given to agricultural education in Uganda than in the other territories. Special provision for professional training in agricultural and veterinary science has been made at the Makerere College, and under this scheme assistants required for the Agricultural and Veterinary Departments receive a five years' course of theoretical and practical training. In

Kenya two agricultural schools have been established for the training of agricultural assistants, and in Tanganyika another school for the training of agricultural assistants required in that territory has recently been started. In Kenya the courses are of three years' duration, whilst in Tanganyika they are for two years. In Nyasaland, Northern Rhodesia, and Zanzibar the training of agricultural assistants is carried on at the Experiment Stations, whilst in Uganda, and more recently in Tanganyika, special model smallholdings have been established for the training of smallholders. In Uganda and Zanzibar agricultural courses for teachers have been provided, and in Kenya five veterinary training centres have been started for the pastoral tribes.

In the *Eastern Dependencies* well-organized agricultural schools exist at Serdang in Malaya and at Peradeniya in Ceylon. These schools provide two-year courses of instruction, which are given in English, and a junior course of one year's duration in the vernacular. Ceylon has also established three farm schools for practical courses of short duration, and in Malaya a farm school has recently been established in Malacca and others are under contemplation if the school in Malacca is successful. In Mauritius a three years' course of diploma standard is provided at its Agricultural College, where special importance is attached to sugar technology. Courses for teachers are provided in Malaya and Ceylon, and in the former dependency special emphasis is given to refresher courses for agricultural assistants and short courses for smallholders.

In the *West Indian Dependencies* a three years' course of diploma standard is provided at the Imperial College of Tropical Agriculture for students from the whole Caribbean area. This course provides for the training of assistants for the Departments of Agriculture in the West Indian Colonies and for the training of assistant managers of sugar and cacao estates. A special course in sugar technology is also provided. A three years' course of instruction is also given at the Farm School in Jamaica, whilst in British Guiana and in some of the islands of the Windward and Leeward groups an apprentice system has been adopted for the training of subordinate officers required by the Departments of Agriculture.

In the *Mediterranean Dependencies* an agricultural school was established in Cyprus for the training of agricultural assistants and teachers. The supply, however, exceeded the demand, and efforts to give an agricultural training to the sons of farmers were not successful in consequence of the backwardness of general elementary education. It was, therefore, decided to close the agricultural school and to concentrate upon the training of agricultural assistants and teachers at the central experiment station.

In *Malta* an agricultural school is shortly to be opened for the sons of farmers, in which the courses will be of short duration during those periods of the year when the young men can be spared from the farms. In Palestine there has been a very great development of agricultural education, especially amongst the Jewish community. This was considered to be essential for an immigrant population largely drawn from urban centres in Europe, and the policy of providing a thorough agricultural

training in the country of their adoption has been fully justified. The youth of Palestine is also being carefully trained in agriculture, and the Government has established large numbers of school gardens or small school farms in association with the elementary schools and two agricultural schools—one for Arabs and another for Jews. There are also eight non-Government agricultural schools, and in 1936 the number of students under training at agricultural schools amounted to 896, of whom 620 were boys and 271 were girls.

In the *Pacific Dependencies* provision is made in Fiji for the training of agricultural assistants and also for the training of Fijian cultivators at the agricultural experiment stations and at centres which have been established by the Colonial Sugar Refining Company.

It has previously been indicated that the varying conditions and circumstances of the different Colonial dependencies have been responsible for development along different lines. The needs of the agricultural communities vary with the conditions, and methods of approach have demanded corresponding variation.

Generally speaking, however, it was found that the first requisite, after Departments of Agriculture had been established, was locally recruited assistants for research and field work in those Departments. More and more it has been realized that agricultural progress depends in Colonial Dependencies upon the work of these locally recruited assistants who are under the supervision of the higher staff, and that as the training of these assistants was improved, the work of the Departments of Agriculture developed and progressed.

In several dependencies this training of assistants was arranged for at the experiment stations, and this system still prevails in Nyasaland, Northern Rhodesia, Cyprus, and Zanzibar. In others definite apprenticeship schemes have been established, and this system is still in vogue in British Guiana and several of the smaller West Indian Colonies. Yet again, parts of the experiment stations have been assigned for the training of assistants or for agricultural schools where a number of selected candidates with the necessary qualifications are trained. Such schools exist in the northern and the southern provinces of Nigeria, in the Gold Coast, and Kenya.

Where estate-agriculture exists a decided demand arises for trained assistants who are capable of performing efficient estate supervision. This demand gives rise to schools where a specialized training is given in estate practices. Where trained students can be readily absorbed these agricultural schools are performing useful service, and those in Malaya, Ceylon, Jamaica, and Mauritius have trained considerable numbers of useful men. The diploma course at the Imperial College of Tropical Agriculture in Trinidad also provides for West Indian requirements. At Makerere, in Uganda, the training courses are of longer duration, and two of the five years of the courses provided for Agricultural and Veterinary Assistants are spent at the experiment stations or in the veterinary laboratories. The numbers under training are limited to the requirements of the two Departments.

Provision for the training of teachers in elementary agriculture exists in Malaya, Ceylon, Uganda, Nigeria, and the Gold Coast. The courses vary in character and in duration. In certain cases the courses provide for a full year's training, whilst in others the courses are only of short duration. In Nigeria this training of teachers at present consists of specially arranged visits to school farms, agricultural experiment stations, or to the Native Administration farms. It is intended, however, to establish in 1937 definite courses of a full year for teachers at two of the experiment stations, at each of which 60 teachers will attend.

Refresher courses for teachers are also provided in Ceylon, Uganda, and the Gold Coast, and in Uganda importance is attached to the work of the teachers in the schools being supervised and followed up by the agricultural officers specially detailed for this service.

The provision of vocational training adapted to the needs of smallholders is a more complex problem, but considerable progress has been made in Uganda and Nigeria. The object is the improvement of the agricultural practice and the consequent raising of the standard of living. To be successful this training must take into full account the conditions and characteristics of the people, and the teaching must be based upon the results of actual experiment and investigation duly put to practical test at experiment stations or on special demonstration plots. The training of farmers in mixed farming and animal husbandry in the northern province of Nigeria has been definitely successful, whilst progress is being made with the work at the Serere and Bukalasa experiment stations in Uganda. In Nigeria the training is given at farm centres where demonstration holdings have been established, and in Uganda a similar system of model holdings has been adopted. In the latter territory pupils are accepted only from districts in which agricultural officers are stationed, so that their supervision after their training has been completed may be facilitated. The agricultural officers assist the trained pupils in the selection of land and in the lay-out of the holding; it is expected that these trained smallholders will in time act as demonstrators, and that satisfactory results will follow their work much in the same way that progressive development in agriculture is following on the work of agricultural demonstrators in southern Rhodesia.

The possibility of extending this system for training smallholders, suitably modified to suit conditions, in other dependencies is worthy of careful consideration.

In Tanganyika a somewhat similar system has been evolved, and it is the definite policy of the Government of that territory to extend the development of adult-training centres at which young men will receive practical instruction in ploughing, crop-rotation, the preparation and use of manure, animal husbandry, and the measures which should be adopted against soil erosion. At these training centres demonstrations are regularly given by agricultural officers, not only to the young men actually working the holdings, but also to other farmers of the districts in which the centres are located.

Farm schools have also been provided in some dependencies for the training of farmers' sons. They exist in Jamaica, Ceylon, and at Sungei

Ujong in Malacca. At the agricultural school at Serdang, in Malaya, a special one-year's course in the vernacular is also provided, and is attended by pupils who subsequently return to their father's holdings.

In Mauritius a training at the College of Agriculture is beginning to be looked upon as a desirable preliminary to a planting career, and the same holds good to some extent in the West Indies in respect of the diploma course at the Imperial College of Tropical Agriculture. In the Far East, also, certain of the larger plantation groups are requiring that the higher estate personnel should have received a training at an agricultural college in Great Britain or the Dominions, and the Incorporated Society of Planters in Malaya provides for certificates of proficiency in planting practice after definite reading courses have been followed.

Importance is increasingly being attached to the provision of facilities for agricultural education, and from the above can be gathered the directions in which developments are taking place. Much thought has also been given during the past ten years to the training of officers for the Colonial Agricultural and Veterinary Services. Scholarship schemes have been established, and it can be claimed that these Colonial Scholarship Schemes have been fully justified by results. Ten scholarships per annum are now provided in agriculture and three in veterinary science. The agricultural scholarships are usually for two years' duration, whilst the veterinary scholarships may extend, according to circumstances, from one to four years. The first year of the agricultural scholarship is now normally spent at post-graduate work at the School of Agriculture, Cambridge, and the second year at the Imperial College of Tropical Agriculture in Trinidad. This College provides special courses for post-graduate training in tropical agriculture, and all Colonial Agricultural Scholars—whether they are being trained in general agriculture or in specialist branches of agricultural science—are required to attend lectures in agriculture, botany, chemistry, entomology, plant-pathology, economics, and tropical hygiene and sanitation. Special emphasis is laid on practical work, and each student is required to investigate a special research problem and to write up a thesis on it at the end of his year's work for the Associateship of the College. Refresher courses are also provided at the College for officers of Colonial Departments of Agriculture, and a number of Colonial Governments have provided special scholarships to enable officers to attend such courses.

Experience has fully demonstrated the value of the training now provided for agricultural officers, and the same importance is now attached to the value of an adequately trained local personnel. Inadequately trained men are of low value, and whereas this applies with emphasis in any technical department it is also becoming recognized that it applies with equal force in the schools, and that if real progress is to be achieved the teachers must be fully equipped in the subjects which they may be called upon to teach. There is an increasing tendency to require that teachers in rural schools should be equipped in agriculture, and a closer co-operation between the Education and Agricultural Departments is to be expected.

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THE COMBATING OF ANIMAL DISEASES AND THE IMPROVEMENT OF STOCK IN EMPIRE COUNTRIES

Pt. II. THE IMPROVEMENT OF STOCK

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To speak of this subject as a problem is, perhaps, wrong; for it is a series of problems. Rival opinions whether the work should be carried out by the veterinarian, the agriculturist, or by a person appointed *ad hoc*, prove only that the position is not thoroughly understood. Administrative officers, educationists, water-engineers, and many others, must all play their parts. It is not simply a question of improving breeds, but of creating conditions under which the improved animals can live and thrive. Naturally, the problems vary according to local conditions, the types and intelligence of the people, the purpose for which the animals are required, and so on. Completely varying conditions are often found in different portions of the same colony. Much of the work required in some colonies must be modified, or can be eliminated in others. Short cuts can be taken and the rate of improvement accelerated. It is proposed, therefore, to treat the subject as though a beginning is to be made in a territory where the majority of the inhabitants are unenlightened and possess indigenous stock of poor quality living under primitive conditions. As the envisaged progress advances, stages will be reached which will, it is hoped, be applicable to conditions in other places.

The initial step should, it is suggested, begin with the educationist in association with the missionary. The efforts of the latter are, quite properly, being devoted to what may be described as the production of a good citizen, in addition to the purely religious work more generally associated with the name. So far as can be seen at present, the basic industry of most of our colonies must be in the future, as in the past, agriculture. To live, man must eat, and, in many places, he still eats in an inadequate manner. Whether it be for some foreseen, or potential, market, or simply for improving the dietary of the people, agricultural education should be included in all school curricula. The bias should be introduced at as early a stage as possible. So to educate a people that the result may be a nation of clerks is a folly which has been recognized, but the task of persuading backward people that the acquisition of information concerning the 'three R's' is only the foundation, and not the ultimate goal, of education has not everywhere been grasped. By means of the pliable minds of the young much may be done. At all schools and mission stations there should be one trained to teach and demonstrate the principles of agriculture and cattle-mastership on lines laid down in an approved curriculum. Work in gardens, and with stock, should be undertaken daily at all places where the latter will live. The rate of improving these animals, and the conditions under which they are kept, should be but slightly in advance of those general in the terri-

tory, and should only advance further with the progress of the community in general. They should be object lessons under conditions which, though in advance of those seen in surrounding herds, are yet within the possibility of those in contact with them to emulate in after life. At this stage, it is not so much the breed or quality of the animals themselves which matters, it is the manner in which they are maintained. To put it another way: bettered animal-mastership must precede breed-improvement. Attention has already been drawn to the indifference which is so often displayed by owners towards the welfare of their stock. There is no question that many owners would like to see some improved animals among their herds, but young and old alike must be taught that these can only follow greater care in management. The work among the young will be materially assisted by the educational methods designed to improve the hygienic conditions of the people themselves. In the case of stock, the argument of increased value will carry no less weight among the more primitive people than it does among the more enlightened. Except where stock cannot live, the training should be upon lines calculated to benefit a small, mixed farmer, for in that direction lies the future of the majority. No matter what be the basic crops, the presence of the herd of cattle is essential for providing food, for work, and for supplying organic manure. The educational system suggested has an added value by reason of the greater potential influence of some of the scholars. Demonstrators for the future guidance of the people will be required. Promising scholars should, at a convenient stage in their education, be transferred to institutions where their technical and practical training will be intensified. Naturally, not all will develop sufficiently well to be used for the purpose indicated, but the remainder will benefit considerably, and, perhaps, form the nuclei of better endeavour in districts.

Where the problems of stock-improvement are being tackled for the first time, it is not necessary to await the results of the education of the young. Training of the older people can begin. Reference has already been made to the dipping-tank and its use in general advancement. In few countries of the Empire is the use of the tank not necessary. The gathering of cattle, owners, and herds at the periodic times provides an opportunity of great value. First of all, the animals themselves can be inspected, wounds dressed, and other ailments treated. The attention of owners can be drawn to matters which are operating against the welfare of their herds. The benefits of the castration of superfluous and undesirable males; the segregation of old cows and immature heifers; the keeping apart from the herd of very young bulls or mature bulls which may be likely to mate with their immediate relatives or progeny, should all unceasingly be pointed out, as should also the necessity for careful selection of grazing-grounds and the reservation of some for certain periods. The veterinary officer in charge of a district, and the stock-inspectors under him, should make their periodic visits to villages and herds as frequent as possible to see that advice is followed and to point out the obvious improvements. They themselves should assist in the work of choosing pastures and sites for enclosures. The advantages of providing adequate shelters for very young calves, of allowing them a

maximum of access to their mothers during their early days, and of running with the cows so soon as they are sufficiently strong, should continually be stressed and demonstrated. It is impossible adequately to detail the thousand and one things which, the eye of a good stockman will see, require alteration, but one thing should continuously and increasingly be insisted upon—the importance of selection. The herds which are under consideration consist, of course, of relatively good, bad, and indifferent animals. Not infrequently, the two latter categories apply to the majority. The foundation of the herds of the future must be laid upon the better animals of to-day. By every possible means must the importance of selecting the bulls from the very best, and the sterilization of the remainder, be stressed. The equal importance of heifer-selection and proper mating must not only be pointed out but advice and assistance in the work must be readily given. Although it is impossible at once to eliminate undesirable cows and heifers, careful selection, and better mastership, will soon bring about obvious improvements in the herds as a whole with a corresponding encouragement. Furthermore, a supply of supplementary foodstuffs, for the period when grazing will be poor or insufficient, is essential. Experience has shown that it is too much to expect that crops will, for a long time, be grown especially for this purpose. There are, however, crop-leavings, now abandoned, which could be stored with little trouble and expense, and a small beginning is possible with hay. To persuade primitive people to go to the trouble of cutting and storing hay will not be easy. Nevertheless, if persuasion results in starting upon a small scale, the results will, in some cases, arouse more than interest. As already stated, the object lesson is the principal thing at first. After that has been achieved, more intensive effort will find a much more encouraging atmosphere which will gradually lead the way to larger scale operations and the crops being grown *ad hoc*. This supplementary feeding can also be arranged for by conserving existing supplies. The countries of seasonal rainfall are usually those in the warmer zones, and the growth of grass, during the hot, wet months, is truly enormous. As the seasons change, the growth is dried to the consistency of hay and provides ideal conditions for fires upon a large scale. The miles of burning grass, in such countries as Africa, Australia, America, and others with tropical or semi-tropical conditions, must be experienced if a sense of the enormous loss they entail is to be realized. Nature endeavours to supply an allowance of foodstuffs for the whole year and very often its destruction could be prevented by quite simple means. Fire-guards can be created in many ways. The simplest, of course, is the burning of grass for a given distance all round the area it is desired to preserve. This should never be attempted unless conditions are ideal and the supply of man-power sufficient to prevent the flames getting out of hand and a general conflagration resulting. The preservation of some areas at the expense of others is not uncommon and often leads to recriminations which quite defeat the desired objective. The dragging of heavy logs around an area, as a preliminary to burning, is crude, but satisfactory. The ploughing of ground, where possible, is the most effective. Fire-guards which simply surround a large area are

insufficient. Others must subdivide the whole, so that an accidental fire may be confined to the smallest proportions. Particularly must care be taken to isolate villages and homesteads from which there is great danger. There are those who advocate grass-burning because of the resultant early springing of shoots. It is not denied that a burning of a small portion of grazing may be of assistance to weak or ailing animals, but continual burning destroys all the better grasses, as only the hardiest can survive. Also, the tender shoots are deprived of the shade and protection under which they would flourish. Lastly, a vast amount of manure, from the rotting, ungrazed portions, is almost entirely lost. At the dipping, or other convenient, centres, instruction should be given in the treatment of hides and skins so that they may obtain the highest possible price upon the market. Much loss is sustained by the present haphazard flaying and drying. Improvements in this direction have been most encouraging in those colonies where instruction is in progress, and are of value in connexion with operations to be discussed later.

All this while, the agriculturist has been busy with his work of discovering the advantageous portions of such crop-rotations as may be practised, trying to eliminate the undesirable ones and to introduce others which will be of benefit to the potential farmer as food or for sale. The greater the variety of crops grown, the more the opportunity of salving crop-leavings, and for introducing others designed to improve the general fertility, and to be available for stock. The agriculturist will be assisted by the stores of manure available from the more frequently moved cattle enclosures, for fertilizer-production is now beginning to take the place of manure destruction. For a variety of reasons, restriction of stock at night (undesirable in principle as it is) must continue for a long time. For the reasons given, however, the practice is important in the general advancement. Together with the botanist, the agriculturist will be at work upon a grass survey and in exploring the possibilities of introducing new varieties. In co-operation with the veterinarian, both will note the effects of such restricted, or rotational, grazing as can be arranged. In his turn, the entomologist and his colleagues will be probing the problem of making available new and extensive grazing areas by the elimination of tsetse fly and many other varieties which are detrimental to the well-being of man and beast in certain areas. Without going into details with which many readers of this article will be familiar, it is hoped that sufficient has been written to demonstrate how closely allied are all the various efforts which are essential in laying the foundations of future development.

At this stage it is proper to introduce a reference to a condition that in many colonies is already causing the utmost misgivings and becoming alarmingly acute. The condition is the destruction which is being caused by soil erosion and resulting in the formation of arid areas. The tendency for overstocking to be followed by soil erosion has been referred to. The matter is of the greatest importance, each day it is becoming more urgent, and yet in too few instances are measures being taken to check it. Many are those who have called, and are still calling, attention to it. The voices are often not heard beyond a purely local radius; the reports

drawing attention to the danger are often confined to those of only local interest. The answer given is usually that the resources of the territory, and particularly the financial ones, are quite insufficient to grapple with the situation. It is not too much to say that the policy we have adopted in some of our colonies, and to which reference has already been made, is to some extent to blame. Already areas have been rendered unfit for carrying stock, or for agricultural operations, and still more are rapidly moving to a similar fate. Many are the wrongs, imaginary or real, to which considerable attention is drawn, but rarely is anything said to make those, either at home or abroad, who can influence events, realize that something must be done at once to stop erosion. It is of little use to spend funds solely upon educating and uplifting a people, some of whom may be faced with actual want by the destruction of areas from which they have drawn supplies. No attempt will be made, in this article, to minimize, or ignore, the magnitude of the task. It will require the best brains and huge sums of money. It must, however, be pointed out that what to-day will cost a shilling to repair, may to-morrow cost a pound, and that the greater the delay the greater will become the problem. No attempt will be made to detail the work which will be necessary to check the danger; indeed, the writer is quite incapable of doing so. Amongst the efforts, however, the reduction of stock per acre, or the improvement of areas so that they will carry more, is of importance. The subject of erosion indicates the necessary co-operation of the water-engineer in stock-improvement. In all areas, conservation, or augmenting, of water-supplies is essential. New supplies, many from underground sources, will have to be arranged for those areas which at present are not available to stock because of the absence of all-the-year drinking facilities.

The foregoing is, it is suggested, a résumé of the preliminary work which is required to ensure conditions that are necessary before breed-improvement is begun. Some colonies are already at this stage; portions of others are nearing it; in many, however, the preliminary work is either in its most initial stages or has not been started. What are the steps which follow the completion of this preliminary work? Once again the problems become varied. In some colonies, or portions of them, the policy to be followed is indicated; in others it cannot be seen; in still others, what appeared to be the policy has had to be reconsidered. Whether the outlook be for dairying, or beef, both must be taken into consideration. There are quite a few who advocate, as the first step in breeding progress, the introduction of bulls of a zebu type. In some colonies, the Afrikander bull of South Africa has been conspicuously concerned. Nevertheless, the writer only agrees with such a policy when it is decided that a short cut may be taken and the preliminary work accompanied by some action in regard to breeding. If selecting indigenous animals has resulted in foundation stock of good, hardy, animals, he advocates a different policy. He would, at a calculated previous date, have imported pure-bred bulls of one of our dual-purpose strains. These would have to be kept under the best conditions possible. The cost of importation is high, and the potential value being great, avoidable risks

cannot be taken with them. These bulls would have been selected for the hardiness of their strain and upbringing. The pampered progeny of show-yard stock would be completely ignored in favour of strong constitution and normal conditions. They would have been mated with carefully selected indigenous heifers and cows, and their male progeny again so mated. The resulting bulls would be issued for use among the herds considered ready for grading. The greatest care should be taken against a tendency towards undue haste. The policy should be very conservative and controlled, in its pace, by the progress made in management, pastures, and the provision of supplementary foodstuffs. The objective must be the introduction of some of the characteristics of the better breed, whilst preserving all the hardiness of the local animal, and allowing further improving mastership to exert its beneficial effect. It is almost certain that progress in pasture, and allied, improvement cannot keep pace with the rate at which the animals themselves can be improved. It may be necessary again to introduce unrelated bulls of no higher grade than those already in service. No rule, other than that of local conditions, can be laid down regarding the grade of bull to be used. Procedure must entirely be governed by general progress, but the fact that haste may mean disaster should always be kept in mind.

In one respect, the writer is not at one with many who are engaged in the work under discussion, and he was greatly encouraged when he found that one of wide experience, and some eminence, agreed with him. It is well known that cattle-improvement, when once started, cannot stand still and mark time. It must progress or retrogress. It is quite a usual thing to try to maintain a certain standard by the use of grade bulls. It is not intended to enter into arguments in this controversy; each must choose for himself the policy he adopts. After a given standard has been reached, the writer would never again use a grade bull. That standard has been reached, and passed, by many enlightened owners, and they have found that their very highly graded stock cannot be maintained, under normal ranching conditions, in some of our colonies. De-grading has become essential and they have introduced graded bulls in the hope of only slightly lowering the quality, and increasing the hardiness, of the animals. The characteristics of our pure-bred animals have been stabilized by generations of breeding and they can be relied upon to appear in the progeny of good sires. Who can say what atavistic abnormalities will follow the use of bulls which have unsettled blood in them? Up to a stage, such bulls must improve the herd; after that they may have an opposite effect. The writer believes that the correct policy is to introduce, each year, a number of selected heifers from less advanced herds. At the same time, a similar number of highly improved animals would be disposed of either by fattening, or, if suitable, for milking. For a very considerable time, such a policy will be possible. Conditions may then allow practically pure-bred animals to thrive. Up to now, only the dual-purpose bull has been mentioned; he can be changed, as circumstances direct, for either a beef or dairy breed. The foregoing indicates a policy which, conservative as it is, may well prove to be too rapid. Arrangements should be made, at the beginning, for maintaining herds

of carefully selected indigenous cows and bulls which would be kept under hardening conditions. Some of the heifers could be put, each year, to the pure-bred bull, so that a supply of hardy second- or third-cross animals may be available to steady the early rate of progress. In another respect these herds will be of value. It is hardly conceivable that some of the transport in outlying districts, now carried out by means of oxen, will be replaced by mechanical traction for very considerable periods. The indigenous is still the only animal which can withstand work over long journeys whilst subsisting upon such grazing as is found upon the way. A supply of these in herds, from which they may be obtained by purchase or exchange, is essential.

Those conversant with the subject may well be thinking, after reading the above, that a policy has been put forward which entirely ignores certain factors that are among the principal stumbling blocks in many colonies. Reference was made earlier to the increased and increasing numbers of really poor animals which are, owing to limited grazing, uncontrolled in-breeding, and other causes, deteriorating still further. The quality of many of these is so poor as to make it almost a sheer waste of time to endeavour to improve them. They cannot be destroyed without compensation, and, if they remain alive, they will continue to breed. It has been stated that quality, not quantity, must be the objective. How can it be attained? Only by improving the selected animal and eliminating the unfit. This can only be brought about by creating a market. The stimulus of progress has always been demand. There is no demand for these wretched animals, and, therefore, one must be created. Simply to destroy them, and compensate the owners, would be to encourage a policy of drift and destroy the value of the educational work advocated. It is suggested that centres should be established, financed by public funds but supervised by men of proved business capacity, for dealing with undesirable animals. At these centres, the hides would be treated by up-to-date methods and graded for sale. The carcasses would then be 'fleshed' and the bones, after sterilization, ground down. The flesh and offal would be boiled, all fat removed, and dried. A portion of the bone-meal could be sold for feeding; the remainder, mixed with the ground flesh and collected blood, put upon the local market as a fertilizer. It is suggested that this fertilizer might well play a part in the general agricultural progress of the territory concerned. The fats would be converted into the cheaper forms of soap and candles for which there is always a steady demand. It may be that experience will show that other valuable by-products may be manufactured at these centres, and attention should be given to the possibilities of utilizing the extracts from certain glands as a valuable side-line. It is many years since the writer first advocated this policy, which was criticized by some as impracticable. Within the last three years a centre was started by the municipality of Nairobi. Reports of the results of the working are available and are so encouraging, both economically and financially, that the Kenya Government has applied for a grant from the Colonial Development Fund for installing larger plants. An announcement in the Press, since this article was begun, states that the application has been successful. The writer

makes no claim that these centres will at once become a source of profit, but the experience at Nairobi demonstrates that, under careful management, they will not be a source of concern to taxpayers. It may well be that unforeseen development will cause them to be of some financial assistance to the other work in progress.

What animals should be treated at these centres? For the time being, and probably for years to come, principally those which are of the greatest potential danger. The itinerant officers, engaged in development, would choose from the herds the poor-quality heifers and younger cows. Older cows, too, would be accepted if the plant was capable of handling the numbers available. Another class of animal will be mentioned later. A hard and fast condition for the purchase from any herd would be to start castrating all male animals not selected by the inspector as adequate for breeding. The centres should be so situated as to allow ample grazing facilities in the vicinity, so that reserves may be established to ensure that operations are maintained at the most economical working rate. Adequate precautions will have to be taken, of course, for protecting the animals, which will have travelled from many sources and over various routes, awaiting slaughter. The dangers will be well known to the administrative veterinary staffs of the territory. Delivery of animals at the centre will be the responsibility of the vendors, who should receive payment when handing over the animals.

There still remains the disposal of the better surplus animals, particularly the bullocks. In many colonies industrial effort has created steady markets which, there is reason to believe, will continue to increase. In certain colonies the demand for good meat is far beyond the power of local sources to meet. In all there is a certain amount of demand. In some of our more backward colonies, however, the total demands are quite inadequate. Here, then, a further demand must be created. An improved dietary is almost always a necessity among backward people. Meat-eating is often a matter of feast or famine. Feast, when rites indicate the killing of stock or when the mortality among animals is high; famine, at other times. Provision for day-to-day consumption is usually lacking. Every effort should be made to foster the habit of consuming meat and milk daily, which is now being stimulated by the increasing industrialism in some colonies. Wherever labour is employed, either domestically or otherwise, it is becoming the practice (often obligatory) to include fresh meat in the daily ration. Those employed go back to their homes with a developed taste which will be satisfied if possible. Most encouraging results have followed an attempt started in Uganda a short time ago. This colony has, as yet, few of the larger industries to employ its surplus population or absorb its produce. Arrangements were therefore made to divert to the more thickly populated areas a movement of cattle, which were slaughtered and sold in joints at markets and other meeting places. The result is an increasing demand in the most unexpected places. New areas are being explored as opportunity admits, and it would appear that this trade may become important. The evidence available to-day shows that the dreams of some can become successful realities if initiative, outlook, and sympathetic co-operation

by those in authority, are assured. Starting in a similar direction to those in Uganda, and in many places assisted by a regular demand from industries, the flow of the better bullocks in the proper directions should be organized and controlled. It may well be that the demand will still be far behind the supply. The less desirable of the better animals must be diverted to the disposal centres where their value will cause them to fetch a better price than the others dealt with; and the local markets must be encouraged to their utmost absorbing power. The benefits are apparent to all. The price paid at the centres will, naturally, vary in different colonies; it may even do so in the various districts of one territory. An ordinary value in one colony might be an absurd one in another. The great thing is that a price of some kind be paid for animals which are at present worthless. The graded stock of enlightened settlers are already being exported, sometimes assisted by the local government. It is suggested that the costs may be lowered, when the time comes, by exporters purchasing the best of the indigenous improved stock for 'finishing' in the more advanced, and particularly the arable, areas. Such a policy might have far-reaching effects.

Up to now only meat-supplies have been discussed. What of dairying? Here again a beginning can and has been made. Creameries should be created in selected areas where there is a large cattle population. The areas will for some time have to be limited to those within easy transport to a railway. The general policy in any country should be dairying in suitable, accessible areas and beef-production in the more outlying parts. Like most other policies it will have to be modified in the light of local conditions. To the creameries would come the daily milk supplies, probably collected from arranged sub-centres. Not only would butter, or ghee, be manufactured, but also cheese and dried milks. Whey and other products would be available for an incipient pig industry, and for the rearing of calves—a task which may have to be delayed owing to the advisability, in some cases the necessity, of leaving calves with their mothers and disposing only of surplus milk. Even at present, however, many settlers could use with advantage such milk products as were available at a reasonable price. Dried milk is, unfortunately, a necessity in many places, and there should be opportunity in the expanding market.

Turning now to the smaller stock. The writer feels that, with the exception of the pig, an attempt should be made to develop these animals in the direction indicated by experience in certain colonies, that is, for the value of their pelts. Indeed, it often appears to be the only justifiable, or possible, one. Sheep should, it is suggested, be encouraged very slowly. It is difficult to see how, in many cases, they could be nursed through the period necessary to fit them for competition in world markets either as mutton or wool. It is realized, of course, that sheep form the majority of the stock of some colonies and that attempts must be made to increase their economic worth. The writer feels that suggestions to this end must come from others more experienced. With goats, it is different. In quite a short time, Nigeria, for instance, has become an influencing factor in the pelt market, and it would appear that more general progress, in this direction, is justified. There is no need to enlarge upon the

necessary steps. Control of diseases, especially those which affect the skin and with which the entomologist is closely concerned; improvement of breed and nutrition; and, finally, carefully supervised treatment and grading of the skins, are the general lines. The importance of further work upon internal parasites must be stressed. In pig-breeding, too, it is thought that a conservative policy should be followed. Some progress may be entirely justified in selected areas, and the pig certainly has a place in the sphere of things when the envisaged small mixed farmer becomes more of a reality than he is. Specialized effort by settlers may also be possible. It is felt by many, however, that the encouragement of the small-animal industry should, in those places where it is only part of the problem and not the only one, proceed upon such conservative lines as will permit further consideration when the outlook becomes more clarified.

Reference must be made to the value of co-operation in stock advancement. The necessity for careful supervision and guidance in some colonies has been emphasized. Those responsible should ever have in mind the binding of all effort in co-operative systems that would include all classes engaged in agriculture. Exploitation of backward by more enlightened people is not unknown; competition from cheap sources may imperil the needed efforts of the more advanced. An endeavour has been made, in this article, to show how a progressive man may assist, and be assisted by, his less advanced neighbour. Adequately controlled co-operation, resulting in mutual benefit, is essential to success.

As previously mentioned, there are people who hesitate to recommend improvement in the animal industry of the Empire. Some of the doubts result from selfish fear; some result from honest consideration; others come from sheer indifference. We have, however, taken upon ourselves to guide the destiny, and influence the future, of many countries. Having created conditions which demand further effort, that effort cannot in common fairness be denied, and the foregoing is a suggestion as to the lines upon which it should be made. The majority of cattle-owners in our colonies are still in a somewhat backward stage. Some are much advanced, but even they have too often neglected the general advance in conditions which are essential to an animal industry. There are sure to be some who disagree with points in the policy outlined; their views may be correct. The purpose of the article is to bring the subject to notice, and, if possible, to arouse that interest in the necessity for action which is too little evident. It is a plea that uncertainties arising from what may happen in generations to come may be put aside, and that an honest effort be made in the right direction, sure in the knowledge that unseen solutions will be found for future problems.

Since the foregoing was written an interesting experiment has been announced from Nyasaland. With a view to bettering the people and the native milk industry, clinics for children have been established at which milk from adjacent herds will be used. Inducements are being offered for quality and continuous supplies. The results of this experiment will be awaited with interest.

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THE CONTROL OF ANIMAL DISEASES IN RELATION TO OVERSTOCKING AND SOIL EROSION

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SOIL erosion has been defined as 'the corrosive action of natural forces on the surface of the earth', and a certain amount of erosion, which in most places is more than balanced by rock decay, is a normal process. To-day, however, the term generally implies an accelerated loss of soil so far above the normal that it constitutes a very serious loss of the natural wealth of many countries. This accelerated loss is almost entirely due to disturbance by man or his domestic animals of the vegetative cover which alone can prevent the shifting of soil by rain and wind.

Throughout the world generally it is probable that injudicious cultivation is by far the most important source of soil erosion, and especially wherever the rainfall is both high and well distributed. Thus Eden [1] in his small monograph on soil erosion gave very little space to damage by stock, and the committee on soil erosion in Ceylon [2] did not mention stock at all.

It is in countries where the rainfall is low, or sufficiently seasonal to permit an annual dry season of several consecutive months, that damage by domestic animals may equal or exceed that done by the cultivator. Thus on page 12 of the Final Report of the Drought Investigation Commission of the Union of South Africa [3] it is stated that 'Deterioration in the vegetal covering of the drier parts of the Union has been brought about mainly through the practices of kraaling, herding, and overstocking, together with an insufficient number of drinking places, and overgrazing'; and on page 15, 'Soil erosion is caused, mainly, by deterioration of the vegetal cover brought about by incorrect veld management.' Also Bennett and Chapline [4] lay the blame for the appalling soil losses which are occurring in the United States of America almost equally on the shoulders of the cultivator and the stockman. We are not concerned, however, with apportioning blame; our present purpose is to emphasize the fact that overstocking is an important cause of soil erosion, and that wherever it exists it calls for serious consideration and scientific intervention. Even in those areas where there is as yet no apparent overstocking, the possibility of its occurrence should be borne in mind, and preventive measures be instituted when necessary.

What is overstocking? A definition which I have given elsewhere [5] is that 'Overstocking is the maintenance of animals on a piece of land to the detriment of its carrying capacity'. In the same article I pointed out that such carrying capacity could be reduced without loss of soil or even of soil fertility, and that, therefore, soil erosion is not an inevitable sequel to overstocking. Nevertheless it is a common sequel, and the one which usually makes the solution of each overstocking problem an urgent

necessity. In every way overstocking is altogether undesirable from the European point of view; an evil which, wherever found, should be removed if possible. The significance of the qualification 'European point of view' will be apparent later.

Since an avowed aim of every veterinary department is the control of animal diseases, particularly epizootic diseases liable to cause widespread and heavy mortality, it would appear that any progress towards the achievement of this aim must tend to increase stock populations, and may lead to overstocking with consequent overgrazing, or to an aggravation of these evils where they exist already. This view of disease-control is taken by many, and a common statement in local reports on soil erosion is to the effect that successful veterinary measures feed the roots of this evil. For example, in the Report of the Native Economic Commission, Union of South Africa [6], on p. 14, we read: 'Measures for combating animal diseases have largely increased the number of cattle. Normally, this should have increased the capacity of the country for carrying population, but the Natives' non-economic cattle outlook caused it to have the opposite effect.' And the Report of the Kenya Land Commission [7], on page 494, states: 'At the beginning of this century, in the country now known as Kenya Colony, the cattle had been suffering for the previous twenty years from a series of disastrous epidemics; in numbers they were comparatively few, and the grazing was more than ample to supply their needs. With the introduction of British Administration, veterinary measures for the control of these diseases were introduced, and by 1920 the cattle population had increased to an estimated total of 3,000,000. Up to that year signs of overstocking and consequent deterioration of land and cattle were hardly noticeable.'

Statements such as these naturally cause a government to doubt whether money allocated to its veterinary department is being spent in the country's best interest, and hesitancy in supporting every activity of their veterinary departments is apparent at the head-quarters of many colonial governments of the present day. It is necessary, therefore, that each veterinary department examine its activities in the light of such criticisms, and ask itself if its policy of disease-control is compatible with a wider policy of rational stocking and soil preservation. Of such supreme importance to every country is its soil, that it is difficult to think of any economic desideratum which might justifiably be purchased by the sacrifice of much of this soil. Certainly the desideratum of disease-control should not be so purchased.

No one, of course, condemns the acquisition of knowledge which alone makes disease-control possible; what is often deplored is the supposedly injudicious application of this knowledge. This critical attitude of mind is rational, and the challenge to veterinary departments is a fair one which must be met.

Having made this general concession, I wish now to say that I believe the challenge is one which can be met by every veterinary department, though naturally I am not in a position to speak for any other country than Tanganyika Territory. On behalf of the veterinary department of

that country I readily accept the challenge, and as conditions there are not unique, it is probable that conclusions of wide application may be drawn from a careful examination of the facts relating to the one country alone.

Overstocking is prevalent in Tanganyika Territory. The area that is stocked to saturation is about 40,000 square miles, and probably 25,000 of these are overstocked, including what was some of the best land of the Lake, Central, Northern, and Western Provinces. The subject has been given much attention and efforts to deal with the problem are being made. It may be said, though, that these efforts amount to no more than a beginning of what requires to be done if the evil is to be removed. In this connexion the recent annual reports of the Department of Veterinary Science and Animal Husbandry should be consulted, particularly the one for 1931, in which Staples deals at length with the problem as it occurs in the important Usukuma district of the Lake Province [8].

As more than 95 per cent. of the stock of Tanganyika Territory is owned by natives, the problem of overstocking in this country may be considered as though it concerned native-owned stock alone.

It is important to note that overstocking is not a new thing in Tanganyika Territory. It is probably as old as animal husbandry itself; certainly it was observed by Stanley when he passed through Usukuma in September 1889. In his *In Darkest Africa* [9] he wrote: 'From our camp we could see the ancient bed of the Lake spreading out for a distance of many miles. Every half-mile or so there was a large cluster of hamlets, each separated from the other by hedges of milk weed. The plain separating these clusters was common pasture ground, and had been cropped by hungry herds as low as stone moss.' On p. 402 he wrote: 'The grass was so short that the cattle were feeding upon the roots to obtain subsistence.'

To some people these paragraphs indicate that overstocking in Usukuma was as bad fifty years ago as it is now, and therefore, as things are not getting worse, there is no need for worry. That this assumption is not justified will be shown later; what does emerge from all the evidence at our disposal is the conclusion that overstocking on a smaller scale existed before the days of European intervention.

How large the evil is at present may be gauged by the statement given above that 25,000 square miles are overstocked. 'It has been calculated that this area is still capable of carrying satisfactorily upwards of two million cattle together with the same number of sheep and goats, and actually it is being asked at present to sustain half as many more. Considering the cattle alone, this means that some 1,200,000 cows and heifers drop 600,000 calves every year on to land of which the carrying capacity is diminishing so that these births must be balanced by at least the same number of deaths from slaughter, disease, and starvation. By the most generous estimate 150,000 is the maximum slaughtered or sold for slaughter, and we cannot avoid the conclusion that an average of at least 200,000 die each year directly or indirectly from starvation. And meanwhile much of the land is steadily or, in places, rapidly, deteriorating' [5].

The primary cause of overstocking is the ordinary desire for wealth acting in communities where wealth is reckoned principally in terms of stock. Subsidiary causes are indifference to the future, and ignorance as to the best ways of achieving the desired wealth. The result is the acquisition by each individual owner of as many animals as possible, with little regard to their quality, less regard to their standard of nourishment, and no regard to the way they deplete the soil. Such a state of affairs in a European community would be reprehensible; in an almost savage community it is not blameworthy but merely deplorable.

One should not deal with the subject of native-owned stock without bearing in mind that, at present, to many natives no form of wealth can replace stock. To quote from Seligman's *Races of Africa* [10]: 'It is impossible to exaggerate the importance of their cattle to the Masai and kindred tribes; not only must their practical function be considered, but also their ceremonial value, indeed the prominence that grass has in ritual among these tribes is due to the fact that it is the food of their beloved animals.

'Among the Suk, and this may be true of the other tribes, cattle are so important that if an adjective stands by itself the noun it qualifies is always understood to be "cow". Again, in Suk even the skin of an ox has a different word to the skin of any other animal, and the verb to drink, if the fluid be milk, is different from the word meaning to drink any other liquid, while an ordinary gourd has a name different from that of one used to collect milk.' Again, on p. 175, Seligman says: 'Among the Dinka there is a well-defined initiation ceremony at which the father of the young man presents his son with a bull, and it is no exaggeration to say that the youth attaches himself so strongly to this animal that the process called by psychologists "identification" takes place; he will pass hours singing to and playing with his bull, he will be known to his associates by the name of his bull, and the death of the latter is a true bereavement. It is not then surprising that cattle are not killed for meat except on ceremonial occasions, the diet of the Nilotes being mainly milk and grain.'

Although the almost religious esteem in which pastoral tribes hold their cattle is weakening under the influence of education, it is still very strong and is never scoffed at by wise administrators. Many of us who have the welfare of the native at heart consider that his desire to possess many stock, if only it could be modified by consideration for the future as well as the present, is excusable, even laudable; as the man who succeeds is then capable of supporting his family in comfort and of contributing towards the public revenue.

The value of stock to the agriculturalist is particularly noticeable when drought, or the threat of drought, occurs during the season of crop growth. At such times people who are entirely dependent on their corn, e.g. those who live in thick tsetse-fly belts, have a very anxious time. On the other hand, it is precisely during these same periods that stock thrive exceedingly, and much compensation for the depreciation of crops is afforded by the evening visits to the cattle-kraal, as the animals come home replete after a warm, dry day amidst abundance of

nutritious, if wilted, grass. For it should be noted that little more than a month's drought in the growing-season may destroy the whole of a grain crop and yet do no permanent injury to grassland—it may destroy or prevent the seeding of many annual grasses, but that is unimportant if the perennials survive, as through these the pasture is replenished by rain coming too late to resuscitate the fields of maize and millet.

This apparent digression was necessary, as it is not uncommon for a European who sees the desolation effected by soil erosion to forget the very real value of native-owned stock, and to think of them only as a pest which is destroying the land. The right conception is that although it is desirable for natives to possess stock, since these are a continual source of nourishment and clothing, and are an economic standby if the grain crops fail, yet it is deplorable that ignorance and indifference should be permitted to turn a laudable industry into an economic disaster. One form in which this ignorance is particularly manifest is the native's apparent inability to realize that his present methods not only make bad provision for the future but are opposed even to his present interests. It is useless to point out to him that greater wealth results from maintenance of a smaller number of animals in good condition all the year round than a larger number in a state of semi-starvation. The truth of this general statement is unaffected by the consideration that most grazing is communal, and therefore the individual would not benefit by a restriction which was not applied to all; and just as true is the statement that the average native cannot grasp the fact that this overstocking is reducing the grazing year by year, so that the total weight of stock which can be carried by any piece of ground must also become less and less. He thus neglects both his own interests and those of posterity.

We can now get an idea of the task which confronts any veterinary department when it is appointed to improve the stock industry of a country containing many native cattle. On the one hand there must be recognition of the fact that domestic animals should be among a country's most valuable assets, and that every native who wishes to possess stock is entitled to attempt to do so, also that the special importance which pastoral tribes attach to cattle must be respected; on the other hand, there is the realization that the natives' present methods of asserting their rights and privileges are prejudicial to general welfare.

A first task of such a department should be a survey of the distribution of stock. When this was done in Tanganyika Territory, a very unsatisfactory state of affairs was revealed.

No less than two-thirds of the Territory were found to be tsetse-infested and therefore free from cattle, and carrying only a sparse population of smaller stock. Two-ninths, although tsetse-free, carried a sparse animal population insufficient for the ordinary needs of the natives of the same areas; and the remaining one-ninth was stocked to saturation.

The next step was to explain this distribution. The reason why the large tsetse-infested area is nearly free from stock is obvious, but the explanation of the distribution of domestic animals on the fly-free areas was obtained only after some years of study, and is briefly as follows:

The two-ninths of understocked country are for the most part high-

lands with granitic soils and a rainfall exceeding 30 in. Possibly the climax vegetation of such country is evergreen forest, but frequently recurrent fires now permit only a sub-climax of grassland or open deciduous savannah. The soils, too, are leached and lateritic. The tall pyrophytic grasses which grow under these conditions furnish very great quantities of potential cattle-food so long as they are immature; after maturity they lose almost all nutritive value, so that animals which are fat at the end of the rainy season lose condition rapidly throughout the cold dry months which follow. The same conditions of close grass-formation and comparatively cool moist climate are very favourable to the extra-host existence of ticks and parasitic worms, so that tick-borne diseases, notably East Coast Fever of cattle, and helminthiases, notably distomiasis of cattle and strongyloses of sheep and goats, are enzootic. Skin diseases, such as streptothricosis and follicular mange, affecting all classes of stock, are also prevalent. The net result is heavy disease-infestation in a low nutritional environment; a state of affairs leading inevitably to small flocks and herds composed of individuals which are heavily parasitized, frequently stunted, and of low fertility. There is usually a high mortality among young stock, and those which survive do so by virtue of acquired immunity to enzootic diseases imposed on an inherited high resistance to these diseases. Few imported animals can survive in such a locality unless they come from somewhat similar environment elsewhere. A somewhat surprising revelation is that although the cattle of these areas show such high resistance to local diseases, they offer little resistance to any unusual epizootic which may arise; for example, an uncontrolled outbreak of rinderpest is usually disastrous in its consequences, and may completely exterminate a local cattle population.

The owners of the animals in these understocked highland areas are entirely unaware of the true causes why their stock do so badly, and they are extremely reluctant to accept any advice as to management which may be offered by a veterinary officer. Throughout the whole of this type of country there is an established equilibrium of low stock-concentrations which, when upset and readjusted, tends more frequently to lower than to higher concentrations. In other words, stock are dying out in some of these areas, and the already large proportion of the Territory which is without cattle tends to become yet larger.

Most of the one-ninth part of the Territory that is stocked to saturation carries a vegetation indicative of arid or sub-arid conditions. Some of it is naturally arid, and comprises open grassland, dry savannah, deciduous thicket, and cultivated land. In this kind of country surface-water is scarce, and stock populations are limited to the numbers which can find a bare livelihood within 15 or 16 miles of water—for to this great distance from water do stock graze in the dry season, drinking every second or even third day. Some of the land that is now sub-arid was not always thus; it has been reduced to this condition by the corrosive action of man's activities.

This condition of artificial aridity reveals an apparent biological anomaly which has been overlooked by most people, although it is of supreme importance in native animal husbandry.

It has been stated earlier that, for the European, overstocking is altogether undesirable; from the native's point of view, however, there is much to be said in favour of overstocking. Knowing nothing of the true cause of disease he yet takes advantage of the important fact that, under East African conditions, the denser a stock population is, the freer is it from disease, so that the healthiest flocks and herds are the ones living on the border line of starvation in arid and sub-arid districts.

I refer to this as apparently a biological anomaly, because the generally accepted view is that overcrowding favours disease. In animal ecology we think of populations of rodents or insects going in cycles; so long as the concentration of a species is low the average individual is healthy, but as numbers increase so disease becomes more rife until it culminates in an epizootic which brings the numbers down to a low level again. So with human beings: when considering problems of public health one accepts as almost axiomatic the view that overcrowding favours disease. Therefore it is at first sight surprising that a concentration of domestic animals high enough to constitute overstocking should be healthy. And very healthy they often are. They almost starve during some months of every year, and they rarely attain their full potential weight, but so well adapted are they to these conditions that, like the dwarf xerophytes which form their sustenance, they react rapidly to the better conditions of the months when food is more available, and during this time they put on flesh and attain breeding condition.

The explanation of the healthiness is to be found by studying the nature of the most devastating stock-diseases of these parts. They are due to parasites which pass part of their existence away from their mammalian host. Such parasites include piroplasms and rickettsia, which are transmitted by ticks, trypanosomes, transmitted by tsetse, and nematodes. Of these transmitters, ticks generally leave their hosts for moulting and egg-laying, and tsetse are attached to their hosts only for brief minutes of feeding. Most parasitic nematodes, too, pass critical stages of their larval life on the ground. The conditions which are most unfavourable to these disease agents are furnished by bare land exposed to the hot sun; conditions which, in Africa, are always associated with aridity. This is explained why the parts of the Territory which are agriculturally the richest are frequently extremely unhealthy for stock, but may be made comparatively healthy by measures which favour erosion and bring about soil aridity even in the presence of good rainfall.

As the environment gets more and more arid from such a cause as overstocking, the animals appear to become smaller rather than fewer. This point is being investigated, but already there is evidence to indicate that the seasonal under-nourishment associated with overstocking tends, through survival of the fittest, to produce a dwarf race of full fertility, but low size-potential, rather than mere stunted individuals of low fertility and retaining a comparatively high size-potential.

This is probably an important point, as combined with the effect on disease-prevalence, it means that this artificial aridity does not readily provide the seeds of its own remedy; the trend is towards a lower and lower equilibrium in which depleted soil is balanced by a more xerophytic

flora and a more dwarf population of domestic animals. In this way we can reconcile the statement of modern economists that the great country of the Wasukuma lying south of Lake Victoria is being turned into desert, with the known fact that Stanley described a scene of obvious overstocking in these parts when he passed through them with Emin Pasha fifty years ago; for there is little doubt that in the areas which were then overstocked the equilibrium between soil, vegetation, and domestic animals was higher than at present. The country *is* on its way to desert, as it was then, but only carefully recorded data, which are non-existent, could show clearly that it is a step nearer to desert now than it was then.

Naturally the native understands nothing of this. He does know, however, that he is continually faced with the alternative of exposing his cattle to the risks of starvation in dry areas, or of exposing them to the risks of such diseases as East Coast Fever in areas where grass is abundant. One might almost say that this is the chief problem in the lives of nomadic pastoral people, though with them the healthy regions are the naturally arid ones of low rainfall.

The real problem of overstocking in relation to soil erosion is furnished by the agriculturalists who are also stock-owners, such as the Wasukuma, to whom reference has been made. These settled in the areas of greater soil fertility and originally, no doubt, lost a good many stock from enzootic diseases. As the direct result of their erosive methods of agriculture and animal husbandry they rendered these areas less fertile but healthier for stock, which consequently increased to, and are now maintained at, saturation point.

This type of abused country is commonly known as *cultivation steppe*, and it exists in patches of varying size in every province. It is associated with a dense concentration of both natives and stock and with comparatively good water-supplies. Its measure is largely the measure of the badly eroded land of the Territory. Not only are conditions within areas of this type getting worse, but the areas themselves are spreading, like ulcers, wherever surface-water permits their peripheries to be extended to meet the growing need of an increasing population driven outwards from centres of ruined fertility.

This analysis of stock-distribution seems to indicate clearly that unaided native husbandry tends to create the two extremes of under- and overstocking. Prior to the European invasion of Tanganyika Territory there were large areas of overstocked land, and enormously larger areas of cattle-free country. Since the arrival of Europeans some formerly cattle-free country has become stocked, but there has been no decrease of overstocking; rather has this evil considerably increased.

As the veterinary department is the branch of government which has most to do with the interests of the stock-owner, and since on our own finding these interests have in some respects deteriorated through increased overstocking, it is natural that the department should be considered as in some measure responsible for the deterioration. This is a reasonable view which does not, however, justify the conclusion that disease-control is the main cause of accelerated overstocking.

The most important diseases of stock in Tanganyika Territory are

rinderpest, contagious bovine pleuro-pneumonia, East Coast Fever, trypanosomiases, anthrax, contagious caprine pleuro-pneumonia, diseases due to worms, and skin diseases. There are about five million cattle and about the same number of sheep and goats, besides donkeys, pigs, dogs, poultry, &c. At the end of 1934 there were only fourteen veterinary officers in the department, including the director and two research officers. Owing to furlough and sickness, there are never more than three-quarters of this staff on duty at one time; that is never more than ten veterinarians to deal with the diseases of ten million stock. They would be rather wonderful men if by their methods of disease-control they were able to cause overstocking.

It is true that the first *aim* of the veterinary department is the application of measures of disease-control to the extent that these are justified economically. I consider that an effort should be made to suppress completely both rinderpest and pleuro-pneumonia, and that staff, knowledge, and funds should be available to allow any other disease to be controlled locally at any time this becomes economically desirable.

But up to now the disease-control measures of the department have perforce been confined to a struggle to keep rinderpest and contagious bovine pleuro-pneumonia within bounds, and to deal with the other diseases when outbreaks assumed excessive local importance. The only significant way in which these attempts have influenced mortality returns is in connexion with rinderpest, so for the purpose of this article we can substitute the term rinderpest-control for the wider term of disease-control, and consider very briefly any effect which such control has had on overstocking.

Rinderpest is a contagious disease capable of infecting most species of ruminants and a few non-ruminants. In East Africa it affects particularly cattle and, among game animals, buffalo, eland, giraffe, kudu, and wart-hog.

Within historic times the disease made its first appearance in Africa south of Egypt about 1889, when infected cattle were brought across the Red Sea from Asia. Once introduced it spread rapidly in the form of the greatest epizootic on record. As it swept through Somaliland (1889), Masailand (1890), Nyasaland (1893), Rhodesia (1896), Transvaal (1896), and Cape Colony (1897), it almost exterminated the cattle and buffaloes in its path. Other game animals also suffered heavily.

So thorough was the destruction, that the epizootic soon died down for want of further large groups of animals to infect, and energetic measures by the governments of all the countries of South Africa succeeded in stamping out the embers. Thus by about 1905 the disease was completely suppressed in all countries south of what is now Tanganyika Territory (then German East Africa), nor, except for a brief incursion into Northern Rhodesia in 1919, has it been allowed to spread south again since. It is one of the main duties of the veterinary department of Tanganyika Territory so to control rinderpest within its boundaries that there is no danger of the disease spreading to its southern neighbours. Total suppression is aimed at but is unachievable with a small staff, and each annual report of the department records the number

of outbreaks dealt with and the number of cattle inoculated. In 1934 there were 44 outbreaks and 130,000 cattle were inoculated.

It must be borne in mind that one attack of rinderpest confers almost lifelong immunity, and, for reasons which need not be discussed here, the form in which the disease occurs to-day in East Africa is much milder than the raging epizootic which worked such havoc in the final decade of last century. It is necessary only to describe what occurs to-day in that part of Tanganyika Territory where the disease is hardly interfered with by the veterinary department. This part is the large and important cattle district of Musoma, lying east of Lake Victoria. Here the disease is always smouldering and sometimes flaring up into outbreaks of considerable size. In the herds where rinderpest is actually active, every susceptible beast, that is every beast which is not immune from a previous attack, may become infected. Some of these die, and some recover, and the disease passes on to other herds, to return again after a period of anything between one and ten years, usually after four or five years.

The most important aspect of this uncontrolled rinderpest is the mortality. Whereas the original epizootic on its way through Africa killed about 90 per cent. of the cattle attacked, to-day in Musoma it kills a mere 5–40 per cent., depending on many factors. This means that when rinderpest is uncontrolled in a district like Musoma, every beast is likely to get it sooner or later, with an expected mortality of 20 per cent.

The normal composition of a Musoma herd of 100 head is 40 cows and 10 adult males, all of which may be immune to rinderpest, and 50 young stock of both sexes, which may be susceptible to the disease. If rinderpest comes along, these 50 become infected and 10 may die. But the 40 cows are capable of rearing 20 calves in a year, so that in the absence of mortality from any other cause the herd could increase even during the year of infection.

Musoma district adjoins Usukuma and resembles it in many ways. Many parts of Usukuma are stocked to saturation, which means that no further increase in numbers can take place—if the herd of 100 is not kept down to 100 by disease and slaughter, starvation will effect the adjustment. But whereas rinderpest takes toll of young vigorous animals, starvation destroys only the weak and aged. Both methods of culling are cruel and deplorable, but starvation does the job better.

Having demonstrated that rinderpest-control has no effect on overstocking, I must add that the main reasons why such control is attempted in most overstocked areas is not for the local effects, but to prevent the disease spreading from these areas, both to other countries and to the understocked parts of the same Territory. In these understocked parts the cattle are so debilitated by enzootic diseases (*vide supra*) that an outbreak of rinderpest may almost exterminate the susceptible animals. Thus a policy of *laissez-faire* with regard to rinderpest merely encourages the inevitable trend of native animal husbandry towards its two extremes of overstocking and complete absence of stock.

I do not say that disease-control never causes or increases overstock-

ing. What I do say most emphatically is that in Tanganyika Territory it does little or nothing towards accentuating the bad conditions in the already overstocked areas. In this Territory, and doubtless in many others, the desideratum of disease-control is *not* being purchased with the indispensable soil.

Pax Europa is the main reason why overstocking has increased so much in East Africa during recent years. Before the settlement of Europeans the history of much of Africa was 'a tangled skein of secessions, wars, migrations, and exterminations' amid which even the strongest tribes had little chance to accumulate stock unmolested for long periods. To-day the weakest tribes tend their animals without fear. Coincident with the first decades of this era of peace was natural recovery of stock populations from the effects of the greatest epizootic of cattle in history.

Summary

Soil erosion is due to the disturbance by man or his domestic animals of the vegetative cover which alone can prevent the shifting of soil by rain and wind.

In many countries with a long annual dry season, overstocking is an important cause of erosion.

Since adequate disease-control tends to increase stock populations, many people have suggested that these measures favour overstocking.

These suggestions naturally raise a doubt concerning the economic value of some phases of veterinary activity in countries where overstocking is rife, and convey a challenge to all veterinary departments.

It would be presumptious for an individual to reply to this general challenge, but the author uses it as a basis for a review of the situation in Tanganyika Territory where overstocking has been prevalent from time immemorial.

The primary cause of overstocking in Tanganyika Territory is the ordinary desire for wealth acting in communities where wealth is reckoned in terms of stock, and where cattle are held in almost religious esteem. Subsidiary causes are ignorance, and indifference to the future.

A brief review of the place which stock occupy in native agriculture is given, and the conclusion drawn that it is desirable for natives to possess stock, but deplorable that ignorance and indifference should be permitted to turn a laudable industry into an economic disaster.

With a view to finding some way of improving the stock industry in the face of many difficulties, the veterinary department of Tanganyika Territory made a survey of the distribution of stock. One most interesting result was the discovery that, generally speaking, the denser a stock population is, the freer it is from disease.

The explanation of this is given, and it is shown that the parts of the Territory which are agriculturally the richest are frequently extremely unhealthy for stock, but may be made comparatively healthy by measures which favour erosion and bring about artificial soil aridity. Unaided native husbandry tends to create the two extremes of under- and overstocking, so that the latter may be considered an essential feature of unaided native husbandry.

In Tanganyika Territory the only form of effective disease-control which can be carried out by a small veterinary staff is rinderpest-control, and the evidence is clear that this does little or nothing towards accentuating the bad conditions of the overstocked areas, since mortality from uncontrolled rinderpest in these areas is less than the usual average wastage from starvation.

In conclusion it is pointed out that the reason for the increase of overstocking in Tanganyika Territory during recent years is *pax Europa*, especially when this had effect at the time when native herds were recovering naturally from losses sustained during the greatest epizootic of cattle in history.

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THE CITRUS INDUSTRY IN SOUTH AFRICA

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WHEN the good ship *Tulp* sailed into Table Bay on June 11, 1654, Governor Jan van Riebeek cannot have imagined that he was laying the foundation of a citrus industry in South Africa, for the ship brought 'orange plants' from the island of St. Helena to him for the newly established gardens of the Dutch East India Company; and these were the first citrus trees to be imported.

It was, however, not until some 250 years later that citrus-growing advanced past the 'trees in the back-yard' stage. The real start of our present industry might be said to date from 1906, when South African citrus fruit made its début at the Exhibition of Colonial Fruits of the Royal Horticultural Society of England, held in London. The possibility of satisfactory shipment of fruit over the long distance of 6,000 miles having been demonstrated, it was not long before commercial shipments were sent on a fairly large scale. From a mere 3,000 cases of citrus fruit shipped in 1907, the annual export, with fluctuations, amounted to 69,000 cases in 1914.

During this period there was no really rapid development at the production end. The extensive planting of trees throughout citrus areas in South Africa, starting shortly after the World War, reached its height in 1924. As the newly planted trees came into bearing the amount of fruit available for export became considerable. As recently as 1921 only a quarter million cases of citrus was exported, but already in 1927 the million mark was approached, the 2-million mark reached in 1930, and in 1934 over 2½ million cases left South African ports for the United Kingdom and Europe.

The export figures do not, however, give a true index of the importance of the citrus industry in South Africa. Although the latest official figures available show that there were over 3 million citrus trees in the Union in 1927, subsequent plantings must have brought the total to well over 4 millions. A conservative estimate would be that 30 to 40 per cent. of the fruit produced is not exported, and thus total production would be over 5 million cases, each of 70 lb. nett. The 2 million white inhabitants of the country consume a considerable amount of citrus, consumption per capita in the Union being at least as high as that in the United States. Unfortunately, the 8 million natives have a very low buying power, and as yet do not constitute an appreciable market for the citrus-grower. Thus the South African citrus industry is based essentially on an export trade, and our main customer is the United Kingdom. Some £20,000,000 is invested in the citrus industry, and this fact helps considerably to place the whole fruit industry second in importance only to wool in the agricultural exports from the Union.

There are two main phases of the industry which assume equal importance. The first is the actual production of the fruit; the second is the packing, transport to the coast, and shipment overseas.

The Growing of Citrus

Experience, though often the best, is a hard taskmaster. South African citrus-growers have learnt most of what they know of the practical side of citrus-growing through their own experience, which has often proved very bitter and costly. This is not said as commendation. Admitting that until recently the grower looked askance at the recommendations of 'experts', governmental and other, it must be realized that those striving for the advancement of the industry were continually faced with the attitude of 'what was good enough for my grandfather is good enough for me'. Fortunately the type of man engaged to-day in citrus-growing is high, and the last ten or fifteen years have seen really remarkable strides in the development of the industry, particularly in respect of production.

The Department of Agriculture may well be proud of its Division of Plant Industry, of which the sections devoted to horticulture, entomology, plant pathology, and low-temperature research have done and are doing much for citrus-growers. Probably the finest example of vigilance by the Department on behalf of growers was their action in 1917 when the prevalence of citrus canker, a dreaded disease of tree and fruit, was discovered in certain parts of the Transvaal. An eradiction campaign was started; at considerable expense and by much thorough work the country was freed of the disease, and the young citrus-industry was saved.

One might say that it is not through such spectacular actions on the part of the Government that soundness is arrived at in any business or industry. Citrus-growing to-day is a business, every whit as much as garment-making or motor-car manufacture is a business. The individual grower has not been in a position to investigate his problems so thoroughly as to make his 'business' fundamentally sound. The Department of Agriculture, realizing the lack of knowledge on the fundamentals of citrus-growing, and knowing that other countries in the world were far in advance of the somewhat primitive methods employed in South Africa, fostered the acquirement of citricultural knowledge from overseas. A leading world-authority on citrus was invited to visit South Africa and report on the industry, and young South African university graduates in horticulture and agriculture were sent overseas to train themselves and study *how* the recommendations given in other citrus areas in the world were arrived at, and to return to their own country and investigate the fundamental problems under South African conditions.

The Subtropical Horticultural Research Station was established in 1927 at Nelspruit in the Eastern Transvaal in the centre of one of the four main citrus-producing areas in South Africa. This station is primarily for the investigation of fundamental problems affecting the production of citrus and other subtropical fruits, and serves the whole of the Union. Its technical staff of eight is investigating such major problems as citrus-manuring, irrigation and soil-moisture relationships, citrus root-stock, and varietal studies, and at the same time has many

minor problems in hand which embrace most of the entomological, pathological, and physiological disturbances encountered by the citrus-grower.

The old hit-or-miss methods of obtaining information on correct practice led to the accumulation of much contradictory so-called knowledge; investigations recently completed, and many others still under way, have done and are doing much to assist in the production of good-quality fruit at the lowest possible cost. The findings of research officers are brought to the attention of growers through such publications as *Farming in South Africa*, and by word of mouth from Itinerant Horticulturists and Extension Officers.

Scientific experimentation with such relatively slow-growing plants as trees is necessarily drawn out over periods of years, so that the existence of many unsolved problems in citrus-growing in South Africa should not be regarded as an indication of lack of endeavour to solve them.

Citrus root-stocks and varieties.—Contrary to what is found in other citrus-growing countries where the sour orange, sweet orange, rough lemon, sweet lime, Rangpur lime, japansche citroen, yuzu, trifoliata, Citrus sunki, and other species are used as stocks, depending on scion variety, the climate, and the soil, only one stock is used in South Africa. Fully 99 per cent. of the budded citrus trees are on the rough-lemon stock, irrespective of the variety of fruit or the type of soil on which the trees are grown.

The sour orange, or Bitter Seville, which is mainly used in most of the chief citrus-growing countries, is for some reason, at present unaccountable, a failure in South Africa. Owing to the great ease of propagation and handling, for the past 30 years nurserymen have used rough lemon exclusively, fearing the sweet orange as a stock because it is highly susceptible to gum diseases under the conditions of orchard management formerly practised. The main problem now under investigation is, (*a*) whether the rough lemon as a group is superior to sweet orange on 'normal' citrus soils; and (*b*), if either group is superior, whether any particular stock within it is better than the rest. This is being determined both qualitatively and quantitatively, the main planting being at the Nelspruit Station, with a replication on a much heavier soil in the Western Transvaal. Minor root-stock problems include the solving of the sour-orange puzzle, which has been described as 'a seemingly physiological impossibility', the finding of a stock suitable for the tangerine group, which does very badly on rough lemon in South Africa, and the comparison of stocks from all over the world with commercial scion varieties on different soil types under different climatic conditions.

Manuring.—This problem is complicated by the fact that citrus is grown in the Union in summer, winter, and intermediate-rainfall areas. In addition, extreme variation in type of soil occurs both in and within the different citrus-producing areas. Information on fertilizer practices to be followed in individual areas and in different sections within such areas is being arrived at through several scientifically laid-out trials conducted in various areas. The Nelspruit Fertilizer Experiment is

mainly for investigating the fundamentals of citrus-manuring. The inherent variability of trees used in horticultural experiments often masks the true influence of differential treatments, and at Nelspruit this variability has been reduced to a minimum. The seed for the stocks was all obtained from one rough-lemon parent tree, a species which gives 95 per cent. apogamically vegetative seedlings; culling in the seed-beds, the nursery rows, and after budding, was extremely severe; and the scion-buds were all cut from one parent tree whose past record was known.

Irrigation.—Practically all citrus grown commercially in the Union is under irrigation. Owing to ignorance of the principles of the water-relations of citrus and of their practical application, for years growers have not only had poor crops but have in many cases lost a large proportion of their trees. Over-irrigation has been the commonest fault, and even where the total amount of water available per annum was insufficient for the acreage planted, it was the incorrect application of this water which indirectly affected the returns of the grower. To-day enlightenment has been given to many, and the thorough investigation of this problem is one of the major projects at the Nelspruit Station. In addition to the practical aspects of irrigation, the physiology of the utilization of water by the citrus tree as related to yield, size, and quality of fruit, root-growth, and root-absorption of plant-foods are receiving full attention.

Among the many minor problems still being investigated are citrus-tree top-working, tree-injection, tree-girdling, mottle-leaf control, artificial coloration of the fruit, chemical identification of citrus species by colorimetric tests, selection of possible future commercial varieties (the Variety Orchard at the Nelspruit Station contains over 200 citrus types and varieties), protection from frost, root-growth studies, and the effects of spraying materials on the quality of the fruit.

Not all experimentation on citrus-growing in South Africa is being done by the Department of Agriculture. The Division of Horticulture of the University of Pretoria has a sub-station in the Eastern Province where much research work is being carried out, whilst the field officers of the South African Citrus Exchange conduct field trials in most areas. The African Realty Trust has its own technical staff to experiment and advise on its holdings, one of which has nearly 600,000 citrus trees in one continuous planting. Not to be forgotten are those progressive growers who, under advice from Department officers, carry out their own experiments on their properties, thereby enabling them to solve difficulties peculiar to individual plantings.

From Tree to Consumer

After having produced the fruit, the growers' concern is to have it delivered to the consumer in the best possible condition. This is rendered all the more difficult because the consumer is so far from the producer. Much citrus is transported 1,200 miles by rail in the Union from the growing-area to the coast, and then travels over 6,000 miles by

ship to its market. In all, at least a full month elapses from date of picking of the fruit until it is consumed.

As soon as the shipment of fruit, both deciduous and citrus, from South Africa to England began to become important, the need of some control on the quality of the fruit exported was felt, as the poor-quality fruit lowered the prices realized for the whole. In 1914 the Union Parliament passed the Fruit Export Act, and this was amended by the Fruit Export Further Control Act in 1929, and qualified by subsequent yearly Government Notices. The export regulations for citrus fruits lay down in detail the type of package to be used, the marks to be carried thereon, the varieties and sizes allowed to be exported, and the external appearance and internal quality of the fruit packed. Most emphasis is laid on the last mentioned. Despite the continued complaint of a certain type of grower at being prohibited from shipping indiscriminately fruit of good and poor quality, the citrus-fruit export regulations are not yet strict enough to allow only fruit equal to the world standard to be exported; but they are being tightened every year, and for the growers' own good, because the Government is mainly concerned with the ultimate benefit to the industry as a whole.

The carrying out of the provisions of the Acts is entrusted to the Perishable Control Board and the Government Fruit Inspector's Office. In addition to inland inspection while the actual packing is being done, final inspection, particularly for waste, is made at the three coastal government Pre-cooling Stores at Capetown, Durban, and Port Elizabeth. Here, after inspection, the fruit is pre-cooled before being loaded into the refrigerated holds of ships.

It was not due to chance that the citrus industry enjoys facilities second to no other country for guarding the produce of the grower from time of packing to delivery overseas. Already in 1924 the Department published the results of observation on ships' chambers cooled by different systems of refrigeration, and work on conditions of fruit prevailing at time of discharge was published in 1932; so that to-day the holds of the ships used for carrying fruit overseas are constructed in accordance with the recommendations made, and a fairly high standard of efficiency in ocean transport has been attained. In 1927 the Low Temperature Research Laboratory was established at Capetown as a section of the Division of Plant Industry. Its sphere of activities embraced (*a*) the cooling of fruit in land stores prior to shipment, (*b*) the transport of fruit in refrigerated holds on board ship, and (*c*) the investigation of biological problems encountered, such as optimum conditions of storage and the keeping-quality of the produce.

The key to successful transport of citrus fruits from grove to market lies in the correct handling of the fruit at picking, cartage to the packhouse, and treatment in the packhouse. This has been fully demonstrated in recent years by researches carried out by the Chief Government Fruit Inspector and his staff. Admitted that even if the pre-cooling and ship-storage conditions be not ideal, owing mainly to the extremely rapid expansion of the volume shipped, the occurrence of wastage and blemishes on fruit after arrival in European markets is mostly caused

by faulty picking and packing of the fruit. The Department is doing all it can to make growers realize that in such a highly capitalized form of agriculture as citrus-growing, whose perishable produce has to be delivered far away from the source of production, nothing but the most up-to-date and best proven methods of handling are applicable.

The report for 1933 of the Low Temperature Research Laboratory gave, among others, results of investigations on air-distribution to pre-cooling chambers, design of expanding fruit-trolley, cooling of open *versus* solid stacked-fruit trolleys, preliminary analysis of the cooling of fruit packages, cooling systems on ships carrying fruit from South Africa, cold injury of navel oranges, a possible method of studying the effect of severe handling of commercial fruit packages on subsequent wastage, fungal invasion of navel oranges, comparison of the Klotz vitality test for lemons with invasion by *P. digitatum* as a means of determining the susceptibility of oranges to wastage, and the relation between fruit package and wastage in citrus fruits. Provided that his fruit is handled properly until it is packed, the South African fruit-grower can be assured that, thanks to the efforts of the Department of Agriculture, it will be delivered to the buyer in the best possible condition.

The Future

The South African citrus industry is fundamentally sound and will endure. Many changes will have to take place, and maybe hard times gone through, but after the large percentage of marginal growers has been eliminated, citrus fruits grown commercially in the Union will hold their own in the open markets of the world. Certain major general problems have to be faced, and these, in the light of present-day experience, are:

1. *What to grow and where to grow it.* We do not yet know what areas in South Africa are best suited to particular varieties of citrus. For example, one area known to produce grape-fruit equal in quality to any in the world has as yet very few plantings in it, whilst much grape-fruit is grown in areas with an unsuitable climate, so that the fruit produced is of extremely poor quality. The varieties grown in many areas will have to be changed gradually; a citrus-producing area should contain mainly those varieties which produce good crops of the highest quality, and ripen at times which enable the fruit to be marketed to the best advantage. Owing to its distance from the United Kingdom and European markets, and the high cost of ocean transport, South African citrus cannot compete with citrus arriving at the same time from Spain, Palestine, the United States, and Italy. The law of supply and demand operates in citrus-marketing as elsewhere. It behoves citrus-growers to consider carefully the yield, quality, and time of ripening of the varieties which they select to grow in their own particular areas.

2. *Production of a high-quality, uniform product.* Growing the correct variety in the area best suited to it will do much towards attaining this aim, but most depends upon the grower himself. Entomological and pathological investigations determine how the grower can produce a

fruit clean in appearance and least subject to break-down or waste after packing, and he must apply the results of such scientific research. The tightening up of the export regulations will allow only good clean fruit to appear on overseas markets, and growers will have to produce fruit of which most will pass these regulations, otherwise forced dumping on the local markets of fruit not up to export standard will seriously curtail their returns.

3. *Increase in yield of fruit per tree.* Every tree-space in a grove should be occupied by a profit-maker or a potential profit-maker. The economics of actual production has been sadly neglected by South African citrus-growers, but to-day world competition has driven prices down so far that the future existence of many growers depends on their obtaining a larger production from the trees they now have. The average production per tree in the Union is remarkably low. Here also the growing of the right variety in the area best suited to it will help much, but for existing groves the two all-important practices of manuring and irrigation will, if properly carried out, go far to solve this problem. Trees growing on marginal land should be removed, and the performance-record of every remaining tree kept to see that it is 'paying its way'.

4. *Correct handling and transport of the fruit.* The makeshift methods prevailing in orchards and packhouses are gradually being replaced by up-to-date methods which have proved to be the best, but there are still too many growers practising the old ways. Once a grower has irreparably damaged his fruit through careless handling in picking, grading, or packing, even perfect treatment between packhouse and final destination will not prevent such a consignment from being sold at a lower price than that obtained for other fruit; and this difference in price, often repeated year after year, may ruin the grower, quite apart from the damage such poor fruit does to the name of South African fruit in general. The Department of Agriculture has done much to improve inspection, pre-cooling, loading into ships, and transport overseas, but difficulties are still encountered, and these have to be overcome.

The future of the citrus industry in South Africa rests with the grower himself. He is receiving and will receive a tremendous amount of assistance from the Government, maybe even far more than is good for him, but it will be both the individual efforts of the grower in his own groves and the combined efforts of the growers in the industry that will make for permanence.

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A SHORT REVIEW OF EXPERIMENTAL WORK ON THE MANURIAL VALUE OF SYNTHETIC UREA

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UREA (synonyms carbamide, 'floramide'), containing 46 per cent. of nitrogen, appeared on the British and American markets in 1926–7; sample consignments had been tested on field crops at Rothamsted in 1921.

Decomposition in the soil.—There is a little evidence, reviewed by H. B. Hutchinson and N. H. J. Miller,[1] that urea is directly absorbed by plants, and Pirschle[2] demonstrates uptake of urea by 14 plants. Direct absorption of urea does not, however, appear to be very important, because urea is rapidly decomposed into ammonium carbonate in the soil. F. Couturier and S. Perraud[3] found in pot experiments that all the urea was converted into ammonia in 24 hours, the rate being slightly retarded at lower temperatures. F. Littauer[4] found that decomposition in a loam occurred in 10 days at 20° and in 28 days at 0° C. A. L. Prince and H. W. Winsor[5] found that urea was nearly equal in availability to sodium nitrate; 90 per cent. of the urea in the soil of pot cultures was converted into ammonia in 5 days and over 50 per cent. in 3 days, except when the soil was acid, when the period was 11 days. T. Gibson[6] found that urea is decomposed under very diverse soil conditions; decomposition may take place readily at 0°–2° C.; pasture soils decompose urea more readily than arable soils. Urea-decomposition is further discussed by H. W. Jones,[7] and by H. Engel and A. Kaufmann.[8]

Experimental Results

The number of accurate fertilizer experiments with urea in any country appears to be small, but results obtained at Rothamsted, the Waite Institute in South Australia, and at a few other centres, indicate that urea has about the same manurial value as ammonium sulphate. Numerous demonstrational trials point to the same result.

Great Britain.—H. V. Garner[9] reports results obtained on replicated plots at Rothamsted with urea applied to potatoes in 1921, to barley in 1921 to 1924, and to winter oats in 1926. (Table 1.)

Urea was again tested against other nitrogenous fertilizers on barley at Rothamsted[10] in 1927, 1928, and 1929. The lay-out comprised four randomized blocks of 12 plots, each 1/40 acre. (Table 2.) Thus, urea, whilst increasing the yield markedly, was rather better than ammonium sulphate at the higher rate of application, but was slightly

[1] *J. Agric. Sci.*, 1911, **4**, 282–302.
[2] *Biochem. Z.*, 1929, **212**, 466–74.
[3] *C.R. Acad. d'Agric.*, 1925, **11**, 492.
[4] *Z. Pflanz. Düng.*, A, 1924, **3**, 65.
[5] *Soil Sci.*, 1926, **21**, 59–69.
[6] *J. Agric. Sci.*, 1930, **20**, 549–58.
[7] *Soil Sci.*, 1932, **34**, 281–99.
[8] *Z. Pflanz. Düng.*, A., 1933, **29**, 1–15.
[9] *J. Min. Agric.*, 1928, **34**, 1053–4.
[10] *Rothamsted Exp. Stat. Reports*, 1927–8, p. 27; 1929, p. 90.

less effective than ammonium chloride. In 1929 a double dressing of urea gave practically the same yield (25·4 cwt. grain per acre) as ammonium sulphate (25·2 cwt.), and a rather lower yield than ammonium chloride (26·2 cwt.) and sodium nitrate (27·8 cwt.). The valuers assessed the 1929 barley crops manured with urea and ammonium chloride at a higher value than the crops treated with ammonium sulphate, sodium nitrate, and cyanamide. Thus urea appears to have about the same manurial value as sulphate of ammonia.

TABLE 1

	Yield of barley per acre							
	1921		*1922*		*1923*		*1924*	
	Grain bush.	*Straw cwt.*	*Grain bush.*	*Straw cwt.*	*Grain bush.*	*Straw cwt.*	*Grain bush.*	*Straw cwt.*
No nitrogen . .	26·1	17·6	25·2	16·8	21·2	14·8	23·9	14·1
Ammonium sulphate .	35·0	23·5	32·3	20·3	22·8	17·9	33·8	19·7
Equivalent urea . .	34·0	23·4	33·4	21·8	24·7	16·1	32·8	19·6

	Winter oats, 1926		
	Grain Bush. per acre	*Straw Cwt. per acre*	*Potatoes, 1921 Tons per acre*
No nitrogen . .	61·1	34·1	2·0
Ammonium sulphate .	69·0	39·2	2·3
Equivalent urea . .	75·1	43·3	2·3

TABLE 2

	1927				*1928*				*1929*	
	Grain bush. per acre		*Straw cwt. per acre*		*Grain bush. per acre*		*Straw cwt. per acre*		*Grain bush. per acre*	*Straw cwt. per acre*
	*Single dose**	*Double dose†*	*Single dose*	*Double dose*	*Single dose*	*Double dose*	*Single dose*	*Double dose*	*Double dose*	*Double dose*
Ammonium sulphate .	34·0	37·8	20·4	22·2	35·5	34·6	32·1	34·5	25·2	24·9
Ammonium chloride .	36·2	47·0	20·0	27·0	34·6	37·5	31·3	36·2	26·2	25·5
Urea . .	32·8	43·8	20·0	24·3	35·0	35·8	31·1	32·8	25·4	24·0
Cyanamide .	36·0	35·8	20·8	20·7	33·4	37·5	28·8	33·8	26·3	25·6
No nitrogen .	23·6		15·4		28·6		24·4		20·1	20·3

* 1 cwt. per acre. † 2 cwt. per acre.

Urea was included in an experiment to compare the action of different nitrogenous fertilizers throughout a rotation at Jealott's Hill[1] from 1932 to 1934 with the following results (Table 3).

Thus, yields from urea did not differ significantly from those obtained with other nitrogenous fertilizers.

Urea compared favourably with ammonium sulphate and nitro-chalk in a rotation experiment begun in 1928 at Craibstone Farm.[2]

[1] *Jealott's Hill Guide to Experiments*, 1935, pp. 43–5.
[2] *Trans. Highland and Agric. Soc.*, Scotland, 1933.

TABLE 3

Year and crop	1932 Mangolds	1933. Oats		1934. Seeds	
		Grain	Straw	Hay (June 4)	Aftermath (Aug. 17)
Treatments	Tons per acre	Cwt. per acre	Cwt. per acre	Cwt. dry matter per acre	
No nitrogen	21·7	14·9	22·9	30·0	3·0
Ammonium sulphate	29·0	19·6	29·5	41·3	3·2
Ammonium nitrate	30·2	18·6	28·0	41·4	2·9
Nitrate of lime	29·3	19·0	29·4	43·5	3·2
Cyanamide	28·0	19·1	27·0	40·1	3·2
Sodium nitrate	29·7	17·7	27·7	43·1	5·4
Nitro-chalk	26·6	18·6	28·7	42·8	3·7
Urea	27·4	19·4	29·2	42·4	3·0
Sig. difference	4·4	3·1	3·8	4·7	3·1

Australasia.—A. E. V. Richardson[1] reports the results of five seasons' experiments at the Waite Institute, South Australia, in which urea produced wheat yields not significantly different from those given by other nitrogenous fertilizers.

TABLE 4

Treatments	Total produce cwt. per acre	Grain bush. per acre	Mean increase due to nitrogen	
			Total produce cwt.	Grain bush.
No nitrogen	33·02	27·99	..	..
Sodium nitrate	45·50	35·62	12·48	7·63
Ammonium sulphate	42·67	33·77	9·65	5·78
Nitro-chalk	43·35	34·12	10·33	6·13
Urea	42·00	33·14	8·98	5·15

A. Y. Montgomery and W. C. Stafford, T. A. Sellwood and K. M. Montgomery[2] describe top-dressing trials on wheat on medium silty loam at a farm in Canterbury, New Zealand, in 1929–30 and 1930–1. There were six nitrogen treatments replicated six times. Yield data indicate that urea was slightly less profitable than ammonium sulphate and sodium nitrate; August application was significantly better than September and October dressings.

Canada.—Successful results with urea are reported from the Kentville Experimental Station,[3] Nova Scotia, where urea gave the highest yields of oats of all nitrogen treatments tested and good yields of potatoes; from Fredericton[4] where urea, in 4–8–6 mixtures applied at 1,000 lb. per acre, compared favourably with ammonium sulphate, sodium nitrate, and nitro-chalk.

[1] *J. Agric. South Australia*, 1935, **38**, 954–71.
[2] *New Zealand J. Agric.*, 1931, **42**, 185–92; **43**, 46–54.
[3] *Kentville Exp. Stat., Rept. of Superintendent for 1930*, pp. 62–3.
[4] *Fredericton Exp. Stat., Rept. of Superintendent for 1929*, pp. 43–4.

N. T. Nelson[1] of the Tobacco Division, Department of Agriculture, Canada, reported the superiority of urea over nitrogenous fertilizers for tobacco in a two-year trial.

United States.—At the Pee Dee Experiment Station[2] on Norfolk very fine sandy loam, urea was tested on Dixie Triumph cotton and Pee Dee No. 5 maize, grown in rotation; the plots (1/20 acre) formed part of a large fertilizer series.

TABLE 5

Source of N in 8–6–4 mixture	*Lb. seed-cotton per acre*						*Relative rating*
	1921	*1922*	*1923*	*1924*	*1925*	*Average*	
Sodium nitrate	1,020	460	1,430	810	1,734	1,091	100
Ammonium sulphate	1,220	420	1,260	810	1,330	1,008	92
Urea	..	340	1,280	1,030	1,584	..	..
No fertilizer	1,100	220	846	400	1,212	756	..
	Bushels of shelled maize per acre						
Sodium nitrate	51	36	34	35	36	38	100
Ammonium sulphate	43	38	36	31	29	35	92
Urea	..	..	34	31	35	..	..

The authors conclude that whilst there is considerable variation from year to year in the relative effects of the different materials, urea compares favourably with the two other fertilizers used.

Results from two experimental centres, one on a coarse sand, and the other on a lighter and less fertile soil, showed little variation in the cotton yields obtained with different nitrogenous fertilizers. J. J. Skinner, C. B. Williams, and H. B. Mann[3] describe experiments on cotton and sweet potatoes carried out on farms in North Carolina where the nine principal soil types of the State were represented. In five of the experiments cotton was grown successfully for two years; in four trials, experiments were for a single year. The yield data indicate that urea is a good fertilizer for cotton and sweet potatoes. It did not injure germination of cotton-seed or the plants in the early stages of growth. There was no indication of unusual leaching from the soil.

The U.S. Department of Agriculture in co-operation with the Maine Agricultural Experiment Station[4] began some field work in Aroostook County, in 1925, to determine the effectiveness of concentrated fertilizers made up with urea on the growth and yield of potatoes in comparison with ordinary fertilizer mixtures. The latter contained cotton-seed meal, dried blood or fish meal, in addition to inorganic N, P, and K. Field plots of $\frac{1}{4}$ to $\frac{1}{2}$ acre were chosen and the fertilizers applied by machine. Yields given on Caribou loam by the concentrated fertilizers, including urea, were comparable with those from the ordinary mixture.

[1] *Canada Dept. Agric., Rept. of Tobacco Division*, 1930, p. 11.
[2] *S. Carolina Agric. Expt. Stat.*, Bull. No. 227, 1926.
[3] *N. Carolina Agric. Expt. Stat.*, Bull. No. 266, 1929.
[4] *Maine Agric. Expt. Stat.*, Bull. No. 350, 1929.

J. D. Harlan and R. C. Collison[1] describe a comparison of nitrogenous fertilizers, including urea, on apple-trees in trials in New York State, begun in 1927. Treatments were replicated six to ten times in each orchard, and results were recorded from 1928 to 1932. Conditions over the orchards varied, but urea appears to have been less effective than sodium nitrate, calcium nitrate, or sulphate of ammonia, between which there were no significant differences.

An experiment with urea on tobacco was begun in 1925 on 1/50-acre plots in fourfold replication at the Windsor Tobacco Station, New Haven, Connecticut.[2] The treatments were: no urea; nitrogen, half as urea and half in the form of cotton-seed meal and castor pomace; all nitrogen as urea. Summarized data of yields and grade indexes over six years were:

	Plots on Field II		*Plots on Field IX*		
	No urea	*½ urea*	*No urea*	*½ urea*	*All urea*
Yield lb. per acre .	1,539	1,457	1,389	1,435	1,452
Grade index . .	0·445	0·444	0·423	0·409	0·393

The conclusion is that urea can be substituted for at least a part of the more expensive organic materials.

In an eleven-year trial of urea at the Maryland Experiment Station[3] urea appeared to be a satisfactory fertilizer for tobacco.

Germany.—Pot and field experiments by E. Haselhoff, O. Liehr, and K. Fluhrer[4] to compare urea with other nitrogenous fertilizers, indicated that urea was equal in value to ammonium sulphate for oats, beets, and other crops. Field experiments on rye, oats, potatoes, and sugar beet at Gross-Lübars and at Lauchstädt[5] to compare urea with other nitrogenous fertilizers applied as a top-dressing in spring gave somewhat disappointing results, particularly on rye. L. Meyer[6] compared urea with other nitrogenous forms at Hohenheim on potatoes and a type of cabbage during the seasons 1925–8. At lower rates of application of nitrogen, urea was slightly less effective on potatoes than ammonium sulphate, but was more effective at all rates on cabbage. Much demonstrational evidence as to the usefulness of urea is available in the German literature, but accurate experiments are lacking.

France.—Pot experiments with urea by Demolon, Brioux, and colleagues[7] gave in general somewhat lower yields than ammonium sulphate and nitrate of soda. Field experiments in several districts of France in which urea was compared with other nitrogenous fertilizers on cereals,

[1] *New York State Agric. Expt. Stat.*, Bull. No. 623, 1933; No. 646, 1934.

[2] *Connecticut Agric. Expt. Stat., Tobacco Stat.*, Bull. No. 8; *Tobacco Sub-Stat.*, Bull. No. 335, 1932.

[3] *Maryland Agric. Expt. Stat.*, Bull. No. 358, 1934; *U.S. Dept. Agric.*, Tech. Bull. No. 414, 1934.

[4] *Landw. Versuchs. Stat.*, 1922, **100**, 37–58.

[5] *Arb. D.L.G.*, 1923, No. 324; *Landw. Jahrb.*, 1925, **61**, 693–5

[6] *Forts. Landw.*, 1929, **4**, 167–9.

[7] *C.R. Acad. d'Agric.*, 1924, **10**, 775–7; 1926, **12**, 195, 898; 1927, **13**, 1017–30.

roots, and tobacco showed little difference between them.[1] In accurate experiments with nitrogenous fertilizers on hops, directed by Prague University,[2] Czechoslovakia, urea gave good yields and was outstanding in giving high-quality hops.

The Tropics.—In eight trials on sugar-cane (bibit) at Pasoerean, Java, in 1921–2, urea compared favourably with ammonium sulphate on light to heavy clay soils.[3] In 57 trials in which urea was compared with ammonium sulphate on cane from the 1923 crop in twelve districts of Java, of varying climate and soil type, response to nitrogen was very marked, but the advantage was always with the sulphate, irrespective of soil type. Urea was judged to be less effective than ammonium sulphate on sugar-cane in Java, and, in addition, its hygroscopicity and package-requirements were not entirely satisfactory.

H. H. Dodds and P. Fowlie[4] report results of a field experiment laid down in December, 1926, with urea and other nitrogenous fertilizers applied to sugar-cane at the Mount Edgecombe Station, Natal. The soil was an acid clay loam (pH 5·5) deficient in all plant-foods. Urea at the rate of 50 lb. N per acre was applied in two equal side-dressings two months and three months respectively after planting. The plots were 1/16-acre each, in fourfold replication. In every instance there was a response to nitrogen, but urea yielded an average increase of only 1·18 t. per acre as compared with 6·36 t. with sodium nitrate, 5·38 t. with whale guano, 3·12 t. with cyanamide, and 2·79 t. with ammonium sulphate. The use of urea was not economic. There was no significant difference in the quality of the cane due to the nitrogen treatments.

J. S. Vollema[5] describes fertilizer experiments on rubber in West Java from 1914 to 1930. One experiment on nursery rubber did not show much response to urea or to any other nitrogenous fertilizer. Five experiments with urea on mature rubber gave positive results; there was not much difference between urea, ammonium sulphate, Chile nitrate, and cyanamide, all giving yield-increases varying from 5 to 25 per cent. In a three-season trial with urea on tobacco at the Deli Experiment Station,[6] Sumatra, on different soil types, urea proved rather less effective than ammonium sulphate; the reaction of the soils was pH 6–7. In field trials on paddy at the Hmawbi and Mandalay Experiment Stations,[7] Burma, urea did not give as large increases, nitrogen for nitrogen, as ammonium sulphate.

Mixed fertilizers containing urea.—*Urea ammonia liquor* is a material developed by E. I. du Pont de Nemours for the manufacture of mixed fertilizers, and consists essentially of a solution of crude urea in aqueous ammonia containing, urea 32·5 per cent., ammonia 28·9 per cent., ammonium carbonate 18·1 per cent., and water 20·5 per cent. It may be used for ammoniating superphosphate in the same way as anhydrous

[1] *Rapport sur le fonctionnement de l'Institut des Recherches Agronomiques pendant l'année 1929*, 113–53.
[2] *Forts. Landw.*, 1927, **2**, 10–15.
[3] *Arch. v. Suikerind.*, 1922, **30**, Pt. I, 958; 1923, Pt. I, 23–35; 1924, **32**, Pt. I, 1.
[4] *Proc. Fifth Ann. Gen. Meeting S. African Sugar Tech. Assoc.*, 1921, 141–9.
[5] *Arch. v. Rubbercultuur*, 1931, **15**, 481–568.
[6] *Med. Deli Proefstation*, 1922, 2nd ser. No. 24.
[7] *Rept. of the Agric. Chemist, Burma, for Year ending March 31, 1929*, 8–11.

ammonia or ammonia liquor. Urea reacts with gypsum in the presence of moisture to set free the water of hydration of the gypsum and form the complex $CaSO_4.4CO(NH_2)_2$, designated *Urea-gypsum.*[1] The material is less hygroscopic than urea. *Urea phosphate*,[2] $CO(NH_2)_2$, H_3PO_4 (N 17·7 and P_2O_5 44·9 per cent.), is prepared by mixing equivalent amounts of its constituents in concentrated aqueous solution with agitation, when it is deposited as a powder of melting-point 117° C. Aqueous solutions in the cold are stable. Work by the Bureau of Chemistry and Soils, Washington,[3] shows that monocalcium phosphate reacts with urea to form urea phosphate and dicalcium phosphate. The reaction can take place when the two solids are mixed in the absence of any visible liquid phase as well as in solution. Mixtures containing excess urea tend to become sticky, whereas with an excess of monocalcium phosphate, mixtures remain dry at ordinary humidities but lose water of crystallization equivalent to the urea present. Urea does not react with dicalcium phosphate but tends to accelerate the loss of water of crystallization from dicalcium phosphate dihydrate at humidities below that corresponding to the vapour pressure of the hydrate. Mixtures of tricalcium phosphate and urea are considerably less hygroscopic than urea if the proportion of tricalcium phosphate is about 80 per cent. or more. *Urea potash phosphate*[4] is a water-soluble complete fertilizer containing 28 per cent. nitrogen, 14 per cent. phosphoric acid (as ammonium phosphate), and 14 per cent. potash as potassium nitrate; 6 per cent. of the nitrogen is present as ammonia, 18 per cent. as urea, and 4 per cent. as nitrate.

Summary

Information on field experiments and demonstrations with urea in the British Isles, Australia, the United States, and other countries is summarized.

Results of replicated experiments over several seasons at Rothamsted Experimental Station, at the Waite Institute, South Australia, at Canterbury, New Zealand, and elsewhere, provide evidence that urea is comparable in effectiveness with ammonium sulphate and ammonium chloride on crops of temperate regions; there is not much experimental evidence on tropical crops, but urea appeared to be less efficient than ammonium sulphate in experiments on sugar-cane in Java and in Natal. Its high analysis, contributing to reduced freight charges, is a point in its favour.

[1] *Ind. Eng. Chem.*, 1933, **25**, 1280–2. [2] *Compt. rend.*, 1932, **194**, 1289–94.
[3] *Ind. Eng. Chem.*, 1934, **26**, 1307–11.
[4] *Die künstlichen Düngemittel*, by von Nostitz and Weigert, Stuttgart, 1928.

(*Received October 29, 1936*)

MULTIPLE-FACTOR EXPERIMENTS ON THE MANURING OF COTTON IN EGYPT

FRANK CROWTHER

THIS paper describes work done under the Joint Research Scheme of the Royal Agricultural Society of Egypt, Imperial Chemical Industries, Ltd., and I.G. Farbenindustrie Aktiengesellschaft. The detailed results of the experiments have already been published as bulletins of the Royal Agricultural Society, under the title of *Experiments in Egypt on the Interaction of Factors in Crop-Growth.*[1]

Until about ten years ago inorganic fertilizers were not considered necessary for the cotton crop of the Nile Delta, where long-staple varieties are grown, and the experimental evidence of Hughes [1] in 1909 and of Prescott [2] in 1924 supported this opinion. Nowadays the use of both nitrogenous and phosphatic fertilizers is increasing rapidly. The former are giving satisfactory returns regularly, but the latter increase the crop only sporadically. This apparent contradiction between experimental and practical results may be ascribed to the changes in the cultivation of the cotton crop which have been introduced since the above-mentioned experiments were made. Pink Bollworm damage, which destroys most of the later crop, is now being checked by the adoption of a closer spacing to give an earlier crop, and by the introduction of earlier-maturing varieties, which although slightly inferior in quality are sufficiently better yielders to justify a preference for them. Presumably both changes have hastened the rate of nutrient-absorption from the soil, for an equal, or even a greater, total amount of nutrient is absorbed within the shortened growing-period. These changes in the cultivation of a crop so commercially important for Egypt as cotton have demanded a re-examination of its manurial requirements. The results of the manurial experiments of the Ministry of Agriculture from 1931–3 were published by Gracie and Khalil [3] in 1935. The experiments under the Joint Scheme were started in 1934 at two centres and extended in 1935 to six centres, of which all except one, Biba, were situated in the Delta.

Design of the experiments.—Cotton in the Delta is sown during March and harvested from August to October. Irrigations from canals are given some eight or ten times during the season.

All experiments were of the randomized-block type and due regard was paid to edge-effects around all plots and along water-channels. An example of a typical lay-out, that of the 1935 Qorashia experiment, is shown in Fig. 1. This experiment comprised the four factors of variety, spacing, nitrogenous and phosphatic manuring, details of which are given in Table 1.

The spacings refer to distances between holes, each of which contained a pair of plants, and the ridges were uniformly 65 cm. apart. Super-

[1] Bulletins 22, 24, 25, 26. Obtainable from the Chemical Section, Royal Agricultural Society, P.O. Box 63, Cairo.

phosphate was applied along the side of the ridges immediately before sowing, and the nitrogenous fertilizer—equal parts of nitrochalk and German nitrate of lime, both 15·5 per cent. N—was applied in two parts, the nitrochalk seven weeks and the nitrate of lime nine weeks after sowing, all in pinches at the base of each pair of plants.

TABLE 1. *Details of Factors of the Qorashia Experiment, 1935*

Variety	*Spacing*	*Nitrogenous manuring*	*Phosphatic manuring*
Maarad	Close: 15 cm.	0 N: nil	0 P: nil
Sakellarides	Medium: 25 cm.	1 N: 100 kg. N-fert. per fed.	1 P: 100 kg. superphosphate per fed.
Giza 7	Wide: 35 cm.	2 N: 200 kg. N-fert. per fed.	
		3 N: 300 kg. N-fert. per fed.	

The 72 treatments were replicated three times within the 216 plots. There were two experiments on this scale in 1934 and four in 1935, together with two smaller ones in the latter season.

Response to Nitrogenous Manuring

The mean yields from nitrogenous manuring expressed as percentages of the unmanured plots were as follows:

TABLE 2. *Yields with Nitrogenous Manuring.* (*Percentage of unmanured*)

1934

	Bahtim	*Gemmeiza*
0 N	100	100
$1\frac{1}{2}$ N	103	119
3 N	104	116
S. error	0·87**	1·78**

1935

	Tukh	*Abu Hammad*	*Qorashia*	*Sakha*	*Mean*	*Abu Qir*	*Biba*
0 N	100	100	100	100	100	100	100
1 N	118	114	107	116	114	($1\frac{1}{2}$ N) 119	($1\frac{1}{2}$ N) 100
2 N	130	127	116	126	125	..	..
3 N	140	133	117	128	130	..	102
S. error	1·33**	2·05**	1·28**	1·60**	..	1·56**	3·19

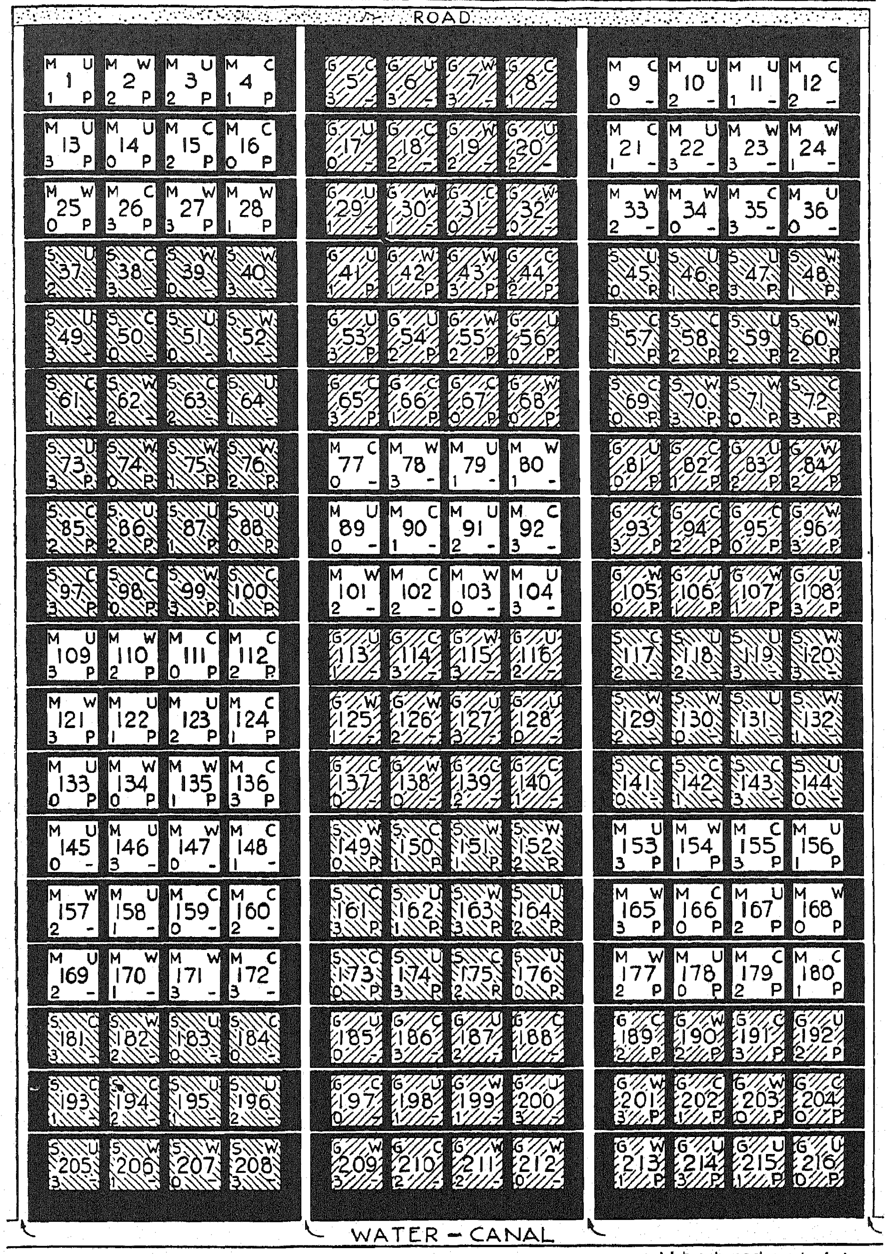
Asterisks show the significance of the effect by the 'z' test, one denoting that it exceeds the 5 per cent. probability-point and two that it exceeds the 1 per cent. point.

In 1934 both experiments showed significant increases with nitrogenous manuring, but $1\frac{1}{2}$ N and 3 N did not differ significantly. Nitrogen-supply was plentiful at Bahtim, but small at Gemmeiza, as the different responses to $1\frac{1}{2}$ N at the two sites confirmed. At Gemmeiza,

FIG. I

LAY-OUT OF QORASHIA EXPERIMENT

SHOWING TREATMENTS OF SEPARATE PLOTS, BELTS, AND WATER-CHANNELS



VARIETY	SPACING	NITROGEN	PHOSPHATE
M • Maarad (unshaded)	C • Close	0 • 0N	– • 0P
G • Giza 7 (hatched)	U • Medium	1 • 1N	P • 1P
S • Sakel (cross-hatched)	W • Wide	2 • 2N	
		3 • 3N	

Water-channels unshaded. Belts are shown black; all were sown with cotton and those surrounding individual plots were cut out before picking

although the soil was deficient in available nitrogen, there was no increased response from $1\frac{1}{2}$ N to 3 N. Examination of the developmental data of the crop showed that this lack of further response arose from the late application of the fertilizer. In the 1934 season all manured plots had received the $1\frac{1}{2}$ N dressing eight weeks after sowing and the heavily manured plots the extra $1\frac{1}{2}$ N three weeks later.

Accordingly, in 1935, fertilizer was applied at all rates in two halves within nine weeks after sowing. The four principal experiments of this season showed very large yield-responses to added nitrogen, the maximum increases varying from 17 to 40 per cent. over those of the unmanured plots. In all four experiments the increases from 1 N and 2 N were profitable, and two experiments gave profitable increases even with 3 N. These increases, which have since been confirmed in the 1936 experiments, are in striking contrast to those of the earlier experiments of Hughes and Prescott since they show that marked changes can occur in the cultural requirements of a crop in the course of a few years. A decade ago nitrogenous manuring of cotton was a failure economically and sometimes even lowered yield by delaying maturation; now nitrogen-supply is one of the most important factors controlling cotton-production.

Response to nitrogen of different varieties.—Examination of the response of the separate varieties to manuring shows how instrumental the introduction of new varieties has been in increasing the effectiveness of nitrogenous fertilizers. The yields of separate varieties with nitrogenous manuring are plotted for each of the 1935 experiments in Fig. 2.[1] The principal experiments in 1934 and 1935 showed significant interaction between variety and nitrogen. The greater response of Ashmouni and of the newer varieties, Giza 7 and Giza 12, over Sakellarides—the favourite Delta variety of a few years ago—is evident from Fig. 2. In general the higher yielders are more responsive to nitrogenous dressings. *Change in variety has, however, increased the response to nitrogen even more than in proportion to the mean yield.* Thus, for example, at Qorashia, without manure Maarad and Giza 7 gave 30 per cent. more crop than Sakellarides, but this proportion did not remain constant for all rates of manuring: it increased with heavier applications, becoming 39 per cent. for 1 N, 44 per cent. for 2 N, and 51 per cent. for 3 N.

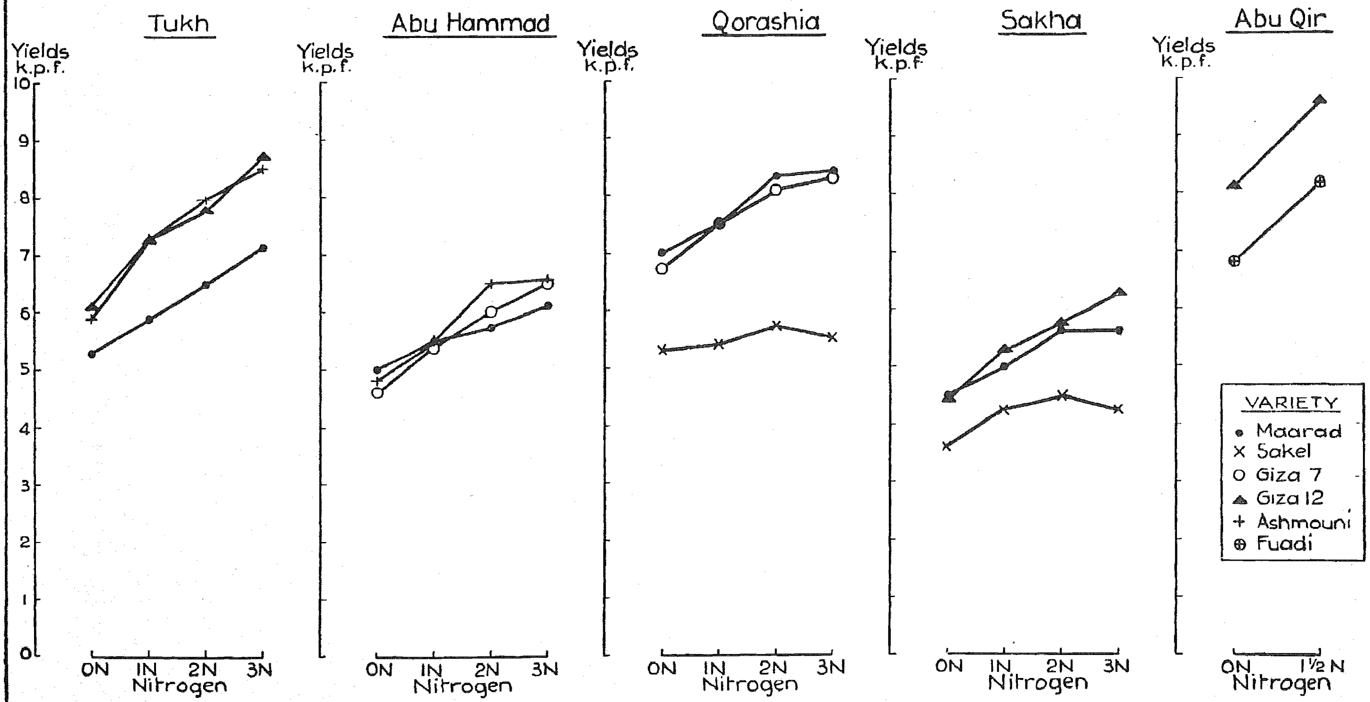
Undoubtedly earlier maturation contributed to this increased response. Developmental data showed that it was not correlated with either increase in amount of vegetative growth or with the proportion of nitrogen to total dry matter within the plant. The most responsive varieties were those with the earliest flower-bud formation, but the subsequent rate of flower-bud production was also involved. Both Maarad and Giza 7 started fruiting before Sakellarides, but Giza 7, which continued to produce fruit more rapidly than Maarad, gave the greater response.

The influence of spacing on response to nitrogen.—The present experiments fully justify the progressively closer spacing of the Delta cotton crop, which has been adopted to maintain yield despite the curtailment

[1] k.p.f. = kantars per feddan.
1 kantar = 312 lb. = 141 kg. (approx.).
1 feddan = 1·038 acres = 0·420 hectares.

FIG. 2

RESPONSE OF THE VARIETIES TO NITROGEN APPLICATION



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N

of the growing-season. The following mean yields for the spacing treatments are expressed as percentages of those of the close spacing:

TABLE 3. *Yields with Different Spacings (Percentages of those for close spacings)*

1934

Spacing	*Bahtim*	*Gemmeiza*
Close	100	100
Medium	103	113
Wide	101	105
S. error	0·86*	1·69**

The spacings between holes were respectively 10, 20, and 40 cm.

1935

Spacing	*Tukh*	*Abu Hammad*	*Qorashia*	*Sakha*	*Biba*	*Mean*
Close	100	100	100	100	100	100
Medium	96	95	96	94	84	93
Wide	93	84	90	93	74	87
S. error	0·92**	1·38**	0·95**	1·13**	2·73**	..

The spacings between holes were respectively 15, 25, and 35 cm.

In 1934 the optimum spacing was slightly wider than 20 cm., in 1935 slightly closer. All five experiments in 1935 gave maximum yields with the closest spacing, and in both seasons medium spacing was superior to wide. The distance between holes at wide spacing represents that general a few years ago, and medium spacing represents approximately the present normal.

The raising of the mean yield-level by close spacing and the presence of more plants per unit area of field suggest conditions favourable to response to nitrogen. The 1935 experiments confirmed this, but the differences were significant in only three out of the six experiments. Table 4 gives the yields in kantars per feddan for the extremes of spacing and nitrogen treatments in these three experiments.

TABLE 4. *Yields with Spacing and Nitrogenous Manuring*

Abu Hammad

Spacing	*Nitrogen* o N	3 N	*Inc.*
Close	5·05	7·14	2·09
Wide	4·39	5·52	1·13
	S. error 0·169**		

Sakha

Spacing	*Nitrogen* o N	3 N	*Inc.*
Close	4·38	5·75	1·37
Wide	4·11	5·03	0·92
	S. error 0·115*		

Biba (Upper Egypt)

Spacing	*Nitrogen* o N	3 N	*Inc.*
Close	3·43	3·95	0·52
Wide	2·98	2·57	−0·41
	S. error 0·177*		

The additional responses to nitrogen with close as compared with wide spacings were respectively 0·96, 0·45, and 0·93 kantars per feddan. The 1934 experiments had failed to show a relation between nitrogen-response

and spacing. The reason for this variability between seasons and within the one season must be sought in the data for the distribution of fruits along the main stem.

The yield of the cotton plant is built up by fruits borne on branches produced successively between the middle and the top of the main stem. Thus the fruits which ripen earliest are lowest down and those higher up mature at a rate dependent upon their position up the main stem. Competition between adjacent plants restricts lateral development of the individual fruiting branches to one or two fruits per branch. Hence the main stem may be regarded as a time-scale with nodes as units of division, the total flower-bud development per main-stem node recording approximately the rate of flower-bud production per plant. Fig. 3 (for Bahtim and Gemmeiza, 1934) shows the potential crop, consisting of flower-buds, flowers, and green bolls in July, and the final crop at the end of the season, consisting only of those bolls which contributed to the crop harvested. The main-stem nodes are grouped in zones of five nodes, labelled zones A, B, C, D, E. The upper diagram shows the effect of spacing and the lower one the effect of nitrogenous manuring. Wide-spaced plants produced more fruit than medium- or close-spaced *in all zones*. Compensation for the fewer plants proceeded therefore throughout the whole period of fruiting. Nitrogenous applications, by contrast, increased the numbers of fruits *only in the upper half of the plant at and above the zone of maximum fruit-development*. Later experiments have confirmed this difference between spacing and nitrogen effects. Considering now its bearing upon the variability in the interaction between the two factors, clearly it is the *position* of the extra crop produced by the spacing and nitrogen treatments, and its ultimate fate, which determine the nature of the interaction. With all spacings there is heavy loss of potential crop, from physiological shedding and damage due to disease. Fig. 3 shows that this is usually heaviest at the upper nodes. In the 1935 experiments Biba, and to a smaller extent Abu Hammad, lost also considerable amounts of fruits from the lower zones. This loss affected the widely spaced plants most, since their additional fruits were borne at all nodes. On the other hand, response to nitrogen was not materially affected, since the additional crop was borne *above* this zone of early shedding. Any shedding at the upper nodes hampers the wide spacings, and also weakens response to nitrogen. In Egypt the most obvious cause of shedding is pest-damage, which varies considerably from season to season and from site to site within any one season. At some sites most of the fruits may be destroyed by leaf-worm (*Prodenia litura*), whereas at others by good control or by good fortune they escape. Pink Bollworm occurs everywhere towards the end of the season, when some fields lose half their crop whilst others lose a negligible amount.

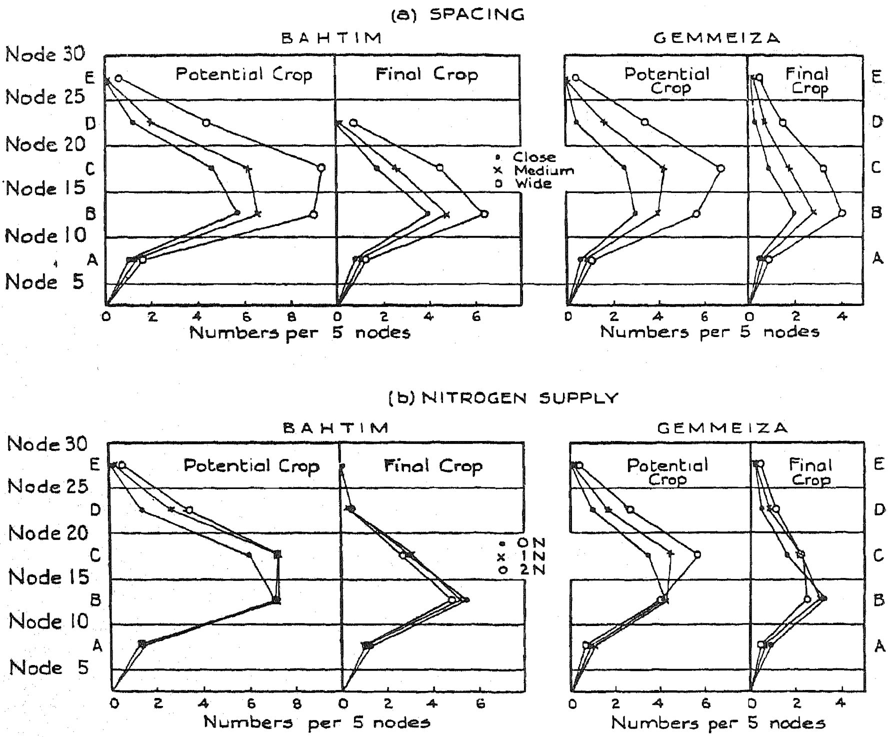
Fruit-shedding is not necessarily unfavourable to response to nitrogen, so long as the upper bolls are not destroyed by Pink Bollworm and are allowed to ripen. The high yields at Qorashia in 1935 resulted entirely from the maturation of the top, late-formed bolls, and the extra bolls with nitrogenous manuring matured at both close and wide spacings.

Biba, on the other hand, experienced heavy early bud-shedding, which hampered the wide spacings and then lost many upper bolls by Pink Bollworm damage. The result was low yields at wide spacings and failure to respond to manuring.

Summarizing these local differences, it seems evident that while pest-damage maintains its present severity in the Delta no constant

FIG. 9

COMPARISON OF (a) SPACING & (b) NITROGEN SUPPLY ON POSITION OF CROP ON THE MAIN STEM



relation between spacing and manurial response is to be expected. Close spacings of about 15 cm. may, however, be relied upon to give as large or larger increases in yield than wide, with nitrogenous manuring up to the maximum rate included in these experiments, i.e. 300 kg. per feddan. Loss of fruit, whether by shedding or by death *in situ*, determines the degree of the inferiority of the wide spacings in both yield-level and manurial response, for the bolls lost are particularly those which represent the additional growth produced by the wider spacing and by the manuring. Even so the greater responses which can be gained by closer spacing are small compared with the improvement wrought by the other important change of the last decade, namely, the introduction of new varieties into the Delta.

The recovery of nitrogen by the crop.—Delta soils vary widely in

available-nitrogen supply. The differences arise partly from variability in soil texture and salt-accumulation, and partly from the effects of crop-rotation. In 1934 the Bahtim experiment was on a soil exceptionally rich in nitrogen, whilst Gemmeiza was on very poor soil. Crops receiving similar cultivation produced abundant vegetative growth at Bahtim, but stunted, yellowish growth at Gemmeiza. Responses to nitrogenous application, given on the optimum date at both sites, were considerably greater at Gemmeiza. The differences in available-nitrogen supply are illustrated by a comparison of the rates of nitrogen-recovery in the two experiments for the extreme-spacing and nitrogen treatments:

TABLE 5. *Rate of Nitrogen-absorption (Kg. nitrogen absorbed per feddan per week)*

Bahtim

Spacing	*Nitrogen*	
	0 N	*3 N*
Close . .	8·62	13·17
Wide . .	6·56	6·94
S. error .	0·488**	

Gemmeiza

Spacing	*Nitrogen*	
	0 N	*3 N*
Close . .	2·40	5·61
Wide . .	2·64	5·20
S. error .	0·188	

The values are for mid-June, the time of maximum rate of absorption. On the richer Bahtim soil the closely spaced plants absorbed nitrogen more rapidly than the widely spaced, but at Gemmeiza they gained no advantage, though there were four times the number of plants, for growth there was governed chiefly by nitrogen-supply. At Bahtim, where the supply was much above the limiting level, vegetative growth proceeded rapidly, especially at close spacing, root-development was encouraged, and more nitrogen was absorbed.

While differences of this order exist it is impossible without previous examination to assess the available-nitrogen supply in the soil and predict probable responses to manurial application. To some extent the richness of a soil persists over several crops, whose development is a rough index of nitrogen-supply. But maize and wheat, which are the most sensitive crops to nitrogen-supply, are not deep 'rooters', and their responses are no guide to the probable responses of cotton whose roots develop in the subsoil.

This is illustrated by the results of an experiment on wheat, which followed the above-mentioned cotton experiment at Bahtim on a third of its area. No fertilizers were applied to the wheat crop, yet the yield was 11 per cent. greater on the plots which had received the single nitrogen-dressing to the previous cotton and 17 per cent. greater on those with the double dressing. The relative response of the cotton crop to nitrogenous fertilizers was thus *less* than that of the following wheat crop to the residues of the fertilizer applied to the cotton.

Moreover, despite a yield response to manuring of only about 3 per cent. the cotton crop recovered 49 per cent. of the amount of nitrogen added in the single dressing, and 33 per cent. of the double dressing.

The following wheat recovered a further 20 per cent. of the nitrogen of both dressings, and yet gave greater yield-responses. Thus it was concluded that there is no necessary relationship between recovery of fertilizer and yield-response.

While it remains so difficult to assess available-nitrogen supply in its relation to the cotton crop, the only course to pursue is to make trials of the manurial requirements of each individual field when it comes under cotton, extending the range to heavy fertilizer dressings where close spacing and the new varieties are being tested. While labour is so plentiful, such trials present little difficulty.

Response to Phosphatic Manuring

The phosphate-requirement of Delta soils is still problematical, for significant responses have not been obtained systematically in experiments. Gracie and Khalil [3] detected significant responses in only ten out of ninety centres. The results of Ahmed Mahmoud [4], on the other hand, show more pronounced responses, and he provides a possible explanation of the existing confusion of opinion about phosphate-requirements by showing that there are pronounced differences in available phosphate-supply even within a single farm.

In the 1935 experiments significant phosphate-responses were obtained at two out of the six centres. In all cases superphosphate was used, for in the alkaline Egyptian soil only the most soluble forms of phosphate prove beneficial. There was no indication of hastened maturation from phosphate-application at either Qorashia or Sakha, where the significant responses occurred. Moreover response to phosphate did not vary with the amount of nitrogen applied. This was unexpected, since there is a general opinion that phosphate-application counteracts the delaying effect of nitrogenous manuring. The varieties differed considerably in their responses, but it would be inadvisable to accept this as a real effect unless it is confirmed by later experiments. The mean yield-increases at Qorashia and Sakha, for the separate varieties, are given in Table 6.

At Qorashia, in the absence of phosphate, Giza 7 outyielded Maarad, but the reverse happened when phosphate was applied. If this effect is substantiated some sources of confusion will have been removed, for at present opinions concerning the phosphate-requirements of cotton are expressed irrespective of variety.

Conclusions

Certain conclusions about the manuring of cotton may be considered as established. There is no doubt that most of the Delta cotton will profit by nitrogenous manuring at medium rates, especially where the newer varieties are grown. The curtailment of the growing-period to avoid bollworm-damage has led to increased responses to nitrogenous fertilizers despite a tendency of these manures to delay maturation. As a corollary it may be inferred that optimum responses will be encouraged by cultivating to obtain rapid early growth of the crop, that is, by adopting such measures as sand-sowing and the additional early water recom-

TABLE 6. *Increase in Yield with Phosphatic Manuring (Qorashia and Sakha)*

(Kantars per feddan)

Variety	*Qorashia*	*Sakha*
Maarad	1·22	−0·17
Sakellarides	0·51	−0·35
Giza 7	−0·54	..
Giza 12	..	0·33
S. error	0·209**	0·100*

mended by the Ministry of Agriculture. Simultaneously the date and method of application of fertilizers should be adapted to accord with these changes; but experimental work on such problems has hardly begun. Moreover, while land drainage remains inadequate over large areas of the Delta, especially in the north, and salt-accumulations form in the surface-soil, it is impossible to do more than foster good early growth by avoiding salt-damage to the very young plants. Large manurial responses were obtained irrespective of whether the soil had been adequately drained or not, but until the major difficulty of large-scale drainage has been overcome, the niceties of the art of manuring must perforce be neglected.

Summary

Results of cotton experiments undertaken by the Royal Agricultural Society, Imperial Chemical Industries, Ltd., and I.G. Farbenindustrie Aktiengesellschaft Joint Research Scheme in 1934 and 1935 on manurial problems are described. The larger increases in the response of cotton to manuring in the Delta in recent years are shown to result primarily from the changes in the cotton varieties and only secondarily from the closer spacings now adopted. The varieties showed large differences in their responses to nitrogenous manuring, some of the newer and more heavily yielding varieties showing greater responses, even on a percentage basis. There was some indication that varieties differed in their responses to phosphates.

Increase in yield from nitrogenous manuring was frequently greater with close than with wide spacing, but there were considerable variations between both sites and seasons, which were explained as the effects of local conditions on the bolls borne successively up the main stem.

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EXPERIMENTS ON THE RELATION OF ENERGY-INTAKE TO LIVE-WEIGHT INCREASE IN FATTENING SHEEP

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THIS report covers six sheep-feeding trials carried out in the years 1934, 1935, and 1936. The general plan was to divide a small flock of sheep into three or four lots, each containing eleven to fourteen animals; a mixed basal ration was offered to all lots and a supplementary ration of concentrates was stepped up, from lot to lot, by intervals of a quarter to a third of a pound per head per day. Any unconsumed food was weighed back. The sheep were weighed at intervals of three weeks throughout the trials and in certain cases the carcass-weights were ascertained. In these cases all the sheep went to the same butcher and were dressed and weighed in the same manner. The animals were housed in an open-fronted shed and, in each case, were given about a fortnight to settle down before the trial began. Water was supplied *ad lib.* and common rock salt was offered, but no other mineral was fed.

Series A (Winter 1933–4)

Forty-eight Kent × Southdown cross tegs were put under experiment in January 1934. The sheep had an average store-weight of about 82 lb. and were presumably about 9½ months old. The basal ration consisted of 1 lb. hay, ¾ lb. flaked maize, and ¼ lb. linseed cake. Clover hay was used in the first half of the experiment and meadow hay in the second; both were of good quality. Lots I and II consumed all but a very little of the hay offered, but Lots III and IV, on the heavier supplementary rations, rejected about 10 and 15 per cent. respectively of the amounts fed.

The supplementary ration consisted of a mixture of three parts flaked maize to one part of linseed cake and was fed at the rate of ⅓ lb. to Lot II, ⅔ lb. to Lot III, and 1 lb. to Lot IV. The four lots had thus, in all, 1 lb., 1⅓ lb., 1⅔ lb., and 2 lb. per head per day of concentrates, respectively. The concentrates were completely consumed by all lots. Some analyses were carried out on the foods; the results of these analyses and the energy-values (starch equivalents) that have been assumed are given in an appendix.

The sheep settled down very well in their pens and spent most of their time feeding or lying down. Lot I, on the basal ration, were occasionally restless before feeding-time. Two ewe tegs turned out in lamb and were removed from the experiment.

Lot IV (on the heaviest ration) were judged to be fat at the end of eleven weeks, and were slaughtered. The average live-weight at this time was about 118 lb. Each of the other lots was carried on until it reached approximately the same average weight of 118 lb., when it was slaughtered. The weight in question was reached by Lot III at 13 weeks, by Lot II in 14 weeks, and by Lot I in 17 weeks.

All the lots made surprisingly rapid live-weight gains, which are

difficult fully to explain. The fleeces undoubtedly gained in weight by an abnormal amount, gathering a very heavy 'yolk'. The percentage of dressed carcass was low, averaging no more than $45\frac{1}{2}$ per cent. It seems probable, therefore, that the live-weight gains exaggerate the amount of progress actually made, though the rate of fattening was in fact very good. In any case comparison of the different lots does not seem to be invalidated by the unexpectedly high general average gain.

The quantities of food actually consumed, per head per day, its estimated total energy-value, and the data of live- and carcass-weights are given in Table 1.

TABLE 1 (*Series A*)

	Lots			
	I	*II*	*III*	*IV*
Food consumed per head per day (lb.):				
Hay	0·98	0·97	0·89	0·85
Flaked maize	0·75	1·00	1·25	1·50
Linseed cake	0·25	0·33	0·42	0·50
Estimated starch equivalent per day	1·16	1·43	1·67	1·93
Estimated starch equivalent per week	8·12	10·01	11·69	13·51
Initial (store) weight (lb.)	81·5	81·9	81·8	81·6
Final (fat) weight (lb.)	117·3	118·2	117·7	118·0
Feeding-period, weeks	17	14	13	11
Live-weight increase per week (lb.)	2·11	2·57	2·71	3·27
Standard error	0·14	0·21	0·15	0·16
Percentage dressed carcass (calculated on unfasted weight)	44·8	45·9	45·1	46·6

The butcher's report on the carcasses was that Lots II, III, and IV were on the average quite fat enough for the ordinary consumer. In Lot I none was too fat and three or four were short of finish.

A calculation of the regression of live-weight increase on estimated starch equivalent gives a figure of 0·202, i.e. each additional pound of starch equivalent produced 0·202 lb. of additional live-weight increase—in other words, each additional pound of gain required an addition of 4·9 lb. of starch equivalent. This figure should not, of course, be compared with those in feeding tables for the energy cost of live-weight increase because, in these tables, the live-weight increase includes both growth and fattening; in the present case the sheep on the lowest plane of nutrition had their growth-requirement more than satisfied.

It will be observed that Lot I (mean or half fat-weight 99·4 lb.) received a ration with an estimated energy-value below Wood's maintenance standard (of 9 lb. S.E. per week) and yet fattened fairly fast. Similar results were obtained in subsequent trials and the point is discussed shortly at the end of this paper.

Series B

A second trial was carried out with shearling sheep in the summer of 1934. The special object was to obtain data for very low levels of nutrition. There were three lots of eleven. The animals were by Suffolk rams out

of Half-bred (Cheviot × Border Leicester) ewes, and were presumably about fifteen months old, in June, when they were put under experiment. The average initial weight was about 86 lb. The sheep were clipped before the trial began. The trial lasted 18 weeks. The basal ration was 1·45 lb. meadow hay, 0·27 lb. linseed cake, and 0·27 lb. flaked maize. Lot II had a supplement of 0·27 lb. and Lot III of 0·54 lb. of flaked maize. The unconsumed residues of food were quite negligible. The sheep showed no particular dissatisfaction with the amount of food, though they were more active than those in Series A. The data of the trial are given in Table 2.

TABLE 2 (*Series B*)

	Lots		
	I	*II*	*III*
Food consumed per head per day (lb.):			
Meadow hay	1·45	1·45	1·45
Linseed cake	0·27	0·27	0·27
Flaked maize	0·27	0·54	0·81
Estimated starch equivalent per day	0·94	1·16	1·39
Estimated starch equivalent per week	6·55	8·14	9·73
Initial weight	86·0	85·6	85·8
Final weight	97·9	104·0	111·6
Live-weight increase per week	0·66	1·02	1·43
Standard error	0·15	0·11	0·13

The results give a close approximation to a straight-line curve and a regression of 0·239 lb. live-weight increase per pound of additional starch equivalent.

The sheep were in fair store-condition at the beginning of the trial and at the end Lot III were fair mutton. Some sheep in Lot II would have passed as fat, and the average might have been described as half-finished. Lot I were thought, on the whole, to have improved in condition, but there is no doubt that the bulk of their live-weight gain was growth. The fleeces would probably have weighed 2–2½ lb. at the end of the trial, representing a live-weight increase of about ⅛ lb. per week. No slaughter weights were obtained.

Series C_1 and C_2

In 1934–5 there was difficulty, owing to the local prevalence of foot-and-mouth disease, in securing a suitable flock of sheep. Eventually a flock of small and badly 'done' Suffolk × Half-bred crosses was bought. The sheep arrived at the farm in distressed and overheated condition, two died of pneumonia, and many of the sheep developed coughs and shed wool. In view of these circumstances it seems unnecessary to give full data of the trials. There were four lots of sheep in each series and the trials ran from January till May.

The sheep in Series C_1 were on rations of hay, linseed cake, and flaked maize, the total concentrate being stepped up from ¾ lb. to 1½ lb. per day, whilst the quantity of hay was kept constant. The regres-

sion figure obtained was 0·15 lb. live-weight increase per pound of additional starch equivalent.

In Series C_2 part of the hay was replaced by marrow-stem kale, and the concentrates were fed in the same quantities as in Series C_1. The regression figure was 0·248 lb. live-weight gain per lb. additional starch equivalent. The curve obtained by plotting the results was, however, very irregular in form.

Series D_1 (1936)

The experimental sheep were a fairly average lot of Kent-bred tegs with an average store-weight of 74 lb. The trial began in January when the sheep were presumably about nine months old. The large majority were first crosses between Southdown and Romney Marsh. A few appeared to be three-parts Southdown. There were four lots of twelve. One sheep in Lot IV died in the course of the trial. There were a few cases of foot-lameness which yielded to treatment, and two of leg-stiffness; the two sheep in question made poor gains, but were retained in the experiment. Otherwise the sheep appeared to thrive quite normally.

The basal ration consisted of $\frac{1}{2}$ lb. clover hay, $\frac{1}{2}$ lb. dried sugar-beet pulp, $\frac{1}{6}$ lb. linseed cake, and $\frac{5}{6}$ lb. of flaked maize. Lots II, III, and IV had additions $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ lb., respectively, of flaked maize. The experiment lasted 15 weeks, and at the end of this time all the sheep in Lot IV and several in Lot III were fat. The remaining sheep were carried on for one or two weeks more, but five sheep in Lot I were still unfinished at the end of the seventeen weeks.

The clover hay was of fair quality, but somewhat mature, and had suffered considerable loss of leaf. The supply gave out three weeks before the end of the trial and a fairly average sample of ryegrass-and-clover was substituted.

Lots I and II rejected only very small quantities of hay and pulp, but Lots III and IV failed to consume all the concentrate during the earlier weeks of the trial. The data are given in Table 3.

The consistency of the results is spoilt by Lot III, which made the same live-weight increase as Lot IV. A prediction based on the gains of the other three lots would have given a figure of about 2·25 lb. per week for Lot III as against an actual gain of 2·56 lb. It is clear from the slaughter data and the dressing percentages that Lot IV made substantially better progress than Lot III, but that this was not reflected in the live-weight increases.

Taking the figures as they stand the regression is 0·235 lb. live-weight increase per pound of additional starch equivalent.

Series D_2

The sheep here used were a random selection from the same flock used in Series D_1, and the rations were the same except that the linseed cake was raised to half a pound and a corresponding reduction made in the ration of flaked maize. All lots had thus half a pound each of hay, beet-pulp, and linseed cake. The rations of flaked maize were $\frac{1}{2}$ lb., $\frac{3}{4}$ lb., 1 lb., and $1\frac{1}{4}$ lb. per head per day respectively for the different lots.

TABLE 3 (*Series D_1*)

	Lots			
	I	*II*	*III*	*IV*
Food consumed per head per day (lb.):				
Hay	0·49	0·49	0·49	0·48
Dried sugar-beet pulp	0·49	0·49	0·49	0·48
Linseed cake	0·17	0·17	0·16	0·15
Flaked maize	0·83	1·08	1·31	1·51
Estimated starch equivalent per day	1·21	1·42	1·60	1·75
Estimated starch equivalent per week	8·47	9·94	11·20	12·25
Initial weight	74·5	74·7	74·4	73·7
Final weight	101·1	104·6	112·9	112·2
Live-weight increase per week	1·77	1·99	2·56	2·56
Standard error	0·18	0·15	0·22	0·22
Number slaughtered at				
15 weeks	0	0	8	11
16 „	2	8	2	..
17 „	5	4	1	..
Unfinished at 17 weeks	5	..	..	..
Dressing percentage of sheep slaughtered	46·2	47·2	47·0	49·1

The rations were more completely consumed than those fed to the lots in D_1. One animal in Lot III died. Otherwise the sheep made steady and satisfactory progress. The data are given in Table 4.

TABLE 4 (*Series D_2*)

	Lots			
	I	*II*	*III*	*IV*
Food consumed per head per day (lb.):				
Clover hay	0·50	0·50	0·49	0·48
Dried sugar-beet pulp	0·50	0·50	0·49	0·48
Linseed cake	0·50	0·50	0·50	0·50
Flaked maize	0·50	0·75	1·00	1·25
Estimated starch equivalent per day	1·99	1·39	1·60	1·80
Estimated starch equivalent per week	8·33	9·73	11·20	12·60
Initial weight	73·9	74·5	73·7	74·3
Final weight	97·3	104·3	107·6	112·2
Live-weight increase per week	1·56	1·98	2·26	2·53
Standard error	0·17	0·14	0·23	0·27
Number slaughtered at				
15 weeks	0	0	6	12
16 „	5	5	3	..
17 „	2	5	2	..
Unfinished at 17 weeks	5	2	..	..
Dressing percentage of sheep slaughtered	47·2	45·5	48·6	49·1

The live-weight increases when plotted against the energy-value of the food consumed give a good approximation to a straight-line curve with a regression of 0·248 lb. live-weight increase per pound of additional starch equivalent.

Discussion

The separate regression figures (lb. gain per lb. additional starch equivalent) found in the six series were 0·202, 0·242, 0·151, 0·248, 0·235, and 0·248, giving a weighted mean of 0·214. If the figures for Series C_1 and C_2 be omitted (for the reason that the sheep were an unhealthy lot) the weighted mean becomes 0·227 with a range from 0·202 to 0·248. Taking the figure of 0·227, the deduction is that a sheep, supposing that its energy-requirements for maintenance, body-growth, and wool-production are already met, requires 4·4 lb. of starch equivalent for each pound of additional gain.

It will be noticed that these figures approach fairly closely to an expectation based on the assumption that the differences in live-weight increase between the different lots in each series were due to the conversion of the varying quantities of surplus energy into pure body-fat. The expectation would be a regression of 0·25, or 4 lb. starch equivalent to each pound of additional live-weight increase.

A further point of interest is whether the regression is on a straight-line curve, or whether there is evidence of a changing rate of conversion at different levels of nutrition. The whole of the results are plotted in Graph 1, where the centre of the figure represents the mean of the energy consumption and live-weight increase of all the sheep in any series. The deviations from the mean starch equivalent of each series are plotted against the deviations from the mean live-weight increase.

In view of the high standard errors of the individual determinations the points fall tolerably well about a straight line. There is no evidence of the operation of 'the law of diminishing returns' at the higher levels of nutrition.

It would seem, then, that the general conclusion from the trials is that, under the conditions of the experiment, about 4½ lb. of added starch equivalent was necessary for each additional lb. of live-weight increase; and that this simple relationship held as between a plane of nutrition that provided for scarcely perceptible fattening and one that permitted of quite rapid progress.

It is, of course, possible that a higher degree of efficiency would be obtained by ensuring a full supply of vitamins, minerals, and a protein mixture of higher biological value. This point is now under investigation.

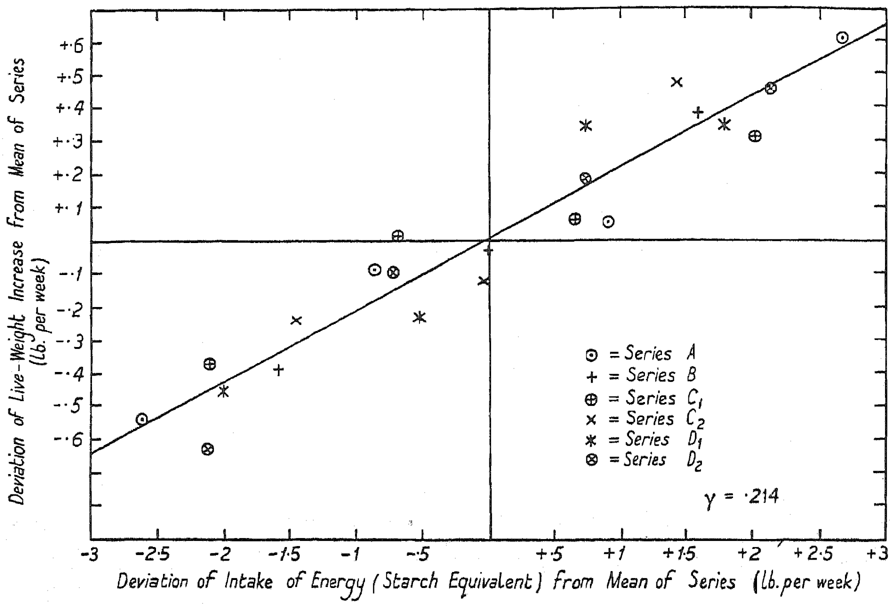
Note on the Maintenance Energy-requirement of the Sheep

It is well known that live-weight-increment experiments cannot be expected to produce precise information regarding the storage of energy in the animal body. Series A provides perhaps an extreme example of their unreliability. Lot I of this series gave a live-weight increase of 2·11 lb. per week and were in fair butcher's condition at the time of slaughter. Yet they gave a carcass percentage of only 44·5 per cent. of their unfasted weight against the ordinarily expected figure, of perhaps 49 per cent. for sheep of about 13 months old in full wool. If we argue back from the actual carcass-weight of 52·4 lb. to a 'true' live-weight (based on 49 per cent. carcass) we get a figure for the fat live-weight of

106 lb., as against the 117 lb. actually recorded. The 'true' live-weight would have implied a weekly live-weight increase of 1·4 lb., as against the recorded increase of 2·11, or an error of 33 per cent.

In the interpretation of these particular experiments there is the further difficulty that no digestibility trials were carried out with any of the foods. This is probably unimportant so far as concerns the concentrates, for the net-energy values of materials like linseed cake and flaked maize vary only within narrow limits. On the other hand, the

GRAPH I



net-energy value of hay varies widely and cannot be accurately assessed either from its appearance, or its botanical or chemical composition, or from all this information combined. Thus, if in Series A the true starch equivalent of the hay had been 40 instead of 35, which was the value assumed on the crude-fibre content and general character of the sample, the weekly consumption of starch equivalent would be wrong by 0·35 lb. This note must be read with the above facts in mind.

If we omit Lot I in Series A, which gave inexplicably high live-weight gains, seven lots of sheep were fed on rations which were estimated to supply about or less than the maintenance energy requirement of 9 lb. of starch equivalent, per 100 lb. live-weight per week, given in Wood's feeding-standard for sheep. The data are given in Table 5.

All these lots gave considerable live-weight increases. Sheep at about the accepted maintenance-level gave increases of from $1\frac{1}{4}$ lb. to $1\frac{3}{4}$ lb. per week. Moreover, all these lots fattened to a considerable extent, as judged by the ordinary methods of handling. Lot B_2, on 8·4 lb. S.E. per week, made a gain of 1·16 lb. and very definitely improved in condi-

tion. Lots C_1 on 7·6 lb. and B_1 on 6·9 lb. were also thought to have fattened to some extent, as well as making growth. At a rough guess, therefore, 6½ or 7 lb. of starch equivalent per 100 lb. live-weight per week provided not only for maintenance but for normal growth, and 9 lb. per week provided for maintenance, growth, and the storage of fully half a pound of fat.

TABLE 5

Series	*Lot*	*Initial weight*	*Final weight*	*Mean weight*	*Estimated starch equivalent consumed per week*	*Estimated starch equivalent per 100 lb. l.-w. per week*	*Live-weight increase per week*
B	I	86·0	97·9	91·5	6·55	6·9	0·66
B	II	85·6	104·0	95·3	8·14	8·4	1·16
C_1	I	66·0	81·8	73·9	6·25	7·6	0·86
C_1	II	66·25	89·2	77·7	7·68	9·1	1·24
C_2	I	66·2	90·0	78·1	7·61	8·9	1·30
D_1	I	74·5	101·1	87·8	8·47	9·2	1·77
D_2	I	73·9	97·3	85·6	8·33	9·2	1·56

Our existing sheep-feeding standards give a constant for maintenance-energy requirement and a factor (which varies with the age of the sheep) for the energy cost of total live-weight increase (i.e. including both growth and fat increments).

The present authors wish to suggest: (1) that the bare maintenance-energy requirement of a growing animal has no real meaning in practice; (2) that it would be sufficient for the purposes of the feeder if he had one figure for maintenance *plus* growth and a second for fat production; and (3) that no single figure for the energy cost of total live-weight increase can possibly hold for different levels of nutrition, since the energy cost of a pound of growth is much less than that of a pound of fat.

They would therefore suggest that energy standards for growing-and-fattening animals might be more logically given in the following form:

Maintenance *plus* normal growth . . . . x lb. S.E.
Fat-production, per pound of live-weight increase additional to growth . . . . y lb. S.E.

In the case of the fattening teg, 9 to 12 months old, they would suggest figures of the order of the following:

Per 100 lb. live-weight

	S.E. per week
Maintenance *plus* normal growth (¾ lb. l.-w. weekly) . .	6–7 lb.
Fat-production, per pound additional live-weight increase .	4–4½ lb.

Alternatively the standards might be given as follows:

Tegs 9–12 months, per 100 lb. live-weight

	S.E. per week
Normal growth (¾ lb. per week)	6·5 lb.
Slow fattening (1½ lb. per week)	9·7 lb.
Full fattening (2¼ lb. per week)	12·9 lb.
Intensive fattening (2¾ lb. per week)	15·0 lb.

If these figures, or anything like them, can be confirmed by further work, they would put a different complexion upon one of the sheep-feeders' problems, viz. that of the relative economy of the fattening sheep at different levels of nutrition. In the following table the 'expected' live-weight increases of a sheep of 100 lb. live-weight, at different levels of energy-intake, are calculated (A) on the figures given in *Rations for Live Stock*[1] (9 lb. S.E. per 100 lb. for maintenance and 2 lb. S.E. per pound live-weight increase), and (B) on the figures set out on the preceding page. In each case the 'gross efficiency ratio' (total energy consumption per pound live-weight increase) is calculated.

	A		B	
Starch equivalent of weekly ration	*'Expected' l.-w. increase lb. per week*	*'Gross' efficiency ratio*	*'Expected' l.-w. increase lb. per week*	*'Gross' efficiency ratio*
10	0·50	1 : 40	1·57	1 : 6·4
11	1·00	1 : 11	1·80	1 : 6·1
12	1·50	1 : 8	2·03	1 : 5·9
13	2·00	1 : 6·5	2·26	1 : 5·8
14	2·50	1 : 5·6	2·49	1 : 5·6

On the first showing a low level of nutrition is extremely uneconomic and a satisfactory gross efficiency can be attained only by intensive feeding. On the other, the level of nutrition is relatively unimportant.

The question of the most economic level of nutrition is receiving a good deal of attention at present. The present authors believe that the value of experiments on the point would be increased if not less than three and preferably four levels of feeding were used in each trial.

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APPENDIX

Composition of Feeding-stuffs used, so far as determined

Hays

		Moisture	*Fibre*	*Assumed starch equivalent*
Series A.	Clover hay	16%	28 %	35
	Meadow hay	12 ,,	31 ,,	35
Series B.	Meadow hay	12 ,,	31 ,,	35
Series D.	Clover hay	16 ,,	30·5 ,,	26

Concentrates

		S.E.
Series A and B.	Flaked maize	84
	Linseed cake (oil 9·6 %)	75
Series D.	Sugar-beet pulp (moisture 15 %, fibre 12 %)	55
	Flaked maize (moisture 13·8 %, oil 3·9 %)	83
	Linseed cake (moisture 9·2 %, oil 9·5 %, crude protein 30·7 %)	73

[1] Ministry of Agriculture, Bulletin No. 48.

THE SOIL-BORNE FUNGUS DISEASES OF FIELD AND PLANTATION CROPS: A REVIEW OF EXISTING CONTROL METHODS

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THE problem of controlling the parasitic fungi causing root-disease in field and plantation crops is one which is common to temperate and to tropical countries alike. To emphasize the widespread occurrence and importance of such diseases, it is necessary to mention only a few examples, such as the root-rots of rubber in Malaya, of tea in India, of cotton in the Sudan, of coffee in East Africa and of cacao in West Africa, of bananas in the West Indies, and of wheat in Canada and Australia.

Fungus diseases of the aerial parts of plants can be controlled by spraying and dusting, whereby the surfaces of the plant are covered with a protective layer toxic to the germinating fungus spores. This protective layer requires renewal, its durability depending upon climatic conditions and other factors [1]. Even tree-crops 60 ft. high can be dusted by modern machines, as in the control of powdery mildew of the rubber tree by sulphur-dusting in Malaya [2]. Another striking innovation, still in the experimental stage, consists in the use of aeroplanes for sulphur dusting against cereal rusts in Canada [3].

No such simple and general method of control has been devised against the fungi causing root-diseases of plants, nor does it appear likely that this is even possible. The difficulties in the way of control are not only technical but also economic, and any fungicidal treatment of the soil on a large scale is generally out of the question on account of the expense involved, even if there were not frequently other objections to the use of soil fungicides. Soil treatments which can be economically applied to highly paying glass-house crops are generally much too expensive for field and plantation crops; methods which are technically possible under the intensive and artificially controlled conditions of glass-house cultivation can find no place in the field.

The ideal method for the control of soil-borne diseases, as of plant-diseases generally, is by the production of resistant varieties of the crop-plant. The production and dissemination of resistant varieties is still more important in such countries as India and Egypt, where much of the agricultural production is in the hands of peasant cultivators, who generally have neither the training, the intelligence, nor the resources to employ more complicated or expensive methods of disease-control. Unfortunately, however, the selection of varieties resistant to disease is generally possible only for the more highly specialized parasites with a very limited host-range.

It is perhaps fortunate for those engaged in crop-production that the majority of the more seriously parasitic root-infecting fungi appear to be so specialized in their mode of life that they cannot multiply on the

soil humus, but can only increase on and in the host-plant. In the absence of appropriate host-plants, therefore, they may be able to persist for some time in the soil, but cannot increase; in the continued absence of host-plants, their decline and eventual disappearance is inevitable. The specialization of these root-parasitic fungi has been fully discussed elsewhere [4]; it is therefore proposed to examine here only its practical implications.

With this in mind, a classification of existing control methods may be made as follows:

1. Methods which are designed to get rid of the fungus during its passive phase in the soil in the absence of host-plants.

2. Methods which check the subterranean activity of the fungus during its active parasitic phase on the roots or other underground parts of the growing crop.

(*a*) Measures designed to increase resistance to attack of the underground organs of the host, where this is possible.

(*b*) 'Rogueing', i.e. the removal of infected plants or parts of plants from the ground in an endeavour to check the subterranean spread of the fungus parasite from infected roots, &c., to healthy roots in contact with them.

(*c*) Measures intended to make the soil environment less favourable for the parasitic activity of the fungus.

3. Methods intended to eliminate as far as possible the dispersal of the fungus to fresh areas by outside agencies, e.g. wind, water, insects, animals, and agricultural practices.

It is not proposed to discuss here in further detail the methods included under the third category, since dispersal may be effected by very varied agencies, and methods of control will obviously vary widely according to the peculiar circumstances of each individual case. Further discussion will therefore be reserved for methods included under the first two categories.

Methods Designed to Eradicate the Fungus during its Resting Phase in the Soil

It will be readily apparent that the problem of root-disease control is more difficult to solve in a permanent or so-called plantation crop, where the parasitic phase of the fungus can last unbroken, than in an area under annual cropping. In the latter case, the period between successive susceptible crops, during which the parasite must enter upon a passive or resting phase, represents a weak point in the economy of the fungus.

The fungus parasite may persist from one susceptible crop to the next in the form of resting spores or other especially adapted survival organs, such as sclerotia, or in infected roots and stubble residues left in and on the soil after the diseased crop. The established method for eliminating such infection from the soil is that of crop-rotation, whereby no susceptible crop is grown for a period sufficient to allow most of the infection to die out from the soil. Reduction of infection to a very low

level, rather than complete eradication of the parasite, generally constitutes a satisfactory compromise.

Since infection has not infrequently been found to survive in the soil for periods of as much as five years after a heavily-diseased crop, control by crop-rotation is not always very satisfactory. It is possible, of course, that such survival may sometimes be only apparent, being really attributable to the carriage of the fungus parasite on susceptible weed-hosts during periods of fallow and alternate crops, or to reinfection of the land from outside sources. Nevertheless, a general search has been made for methods whereby the death of the fungus in such infected soil may be artificially accelerated. Under the intensive system of glass-house cultivation, steam-sterilization of the soil is very generally practised [5]; one serious disadvantage of this method is that the soil is rendered much more favourable for the renewed activity of the fungus parasite, if accidentally reintroduced through infected plants or cuttings, subsoil, walls of beds, or pots. Both for field and glass-house crops, chemical sterilization of the soil has been not infrequently advocated. Experimental field trials have rarely given satisfactory results, though the method has found a certain popularity for the control of insect pests difficult to eradicate in any other way [6]. Disadvantages of soil fungicides are the expense of treating large areas, the fact that the initial concentration of the toxic chemical is rapidly reduced by the soil, and the fact that the killing agent can rarely reach fungus mycelium buried at all deeply in infected plant-residues. Yet other objections can be brought forward, but those already raised constitute a strong deterrent to the use of this method.

More attention might well be paid, therefore, to the operation of natural agencies in effecting the disappearance of parasitic fungi from the soil in the absence of their host plants. It was originally considered that a parasite disappeared from the soil solely through starvation in the absence of an appropriate host; it is now known that such disappearance may be greatly hastened by the antagonism to the parasite of the saprophytic fungi and bacteria of the soil, which attack and decompose it during its resting phase. It has been shown experimentally that this antagonistic action of the soil saprophytes can be increased in various ways; their activity is especially accelerated by the addition of suitable organic matter to the soil, on which they can feed and multiply. It seems very possible that, with further experimental work, such expedients can be adopted as a means for shortening the period of fallow or alternate cropping necessary for the eradication of a fungus parasite from the soil after a diseased crop. Such a method can be fitly termed 'biological control'.

In certain classes of root-infecting fungi, e.g. the smuts and *Fusarium* seedling-blights of cereals, survival in the soil from one season to the next may often be inappreciable, but the fungus is carried over the break from one crop to the next on or in the seed; under local conditions unfavourable to the survival of soil infection, therefore, control of such seed-borne diseases can be obtained by seed-treatment with a disinfectant dust or steep, or with hot water. The practice of seed-treatment,

with especial reference to cereals, has been recently reviewed by Leukel [7].

In permanent or plantation crops, on the other hand, there is no such break in the continuity of the parasitic existence for a root-infecting fungus. Greater attention must therefore be paid to securing a clean start on land destined for a plantation crop. Especially is this the case with tropical crops, which are more often than not planted on the site of cleared jungle. Root-disease trouble in developing plantations is generally a direct legacy from the original jungle. The root-disease fungi exist in biological equilibrium with their hosts in the natural jungle, and nowhere is infection very apparent. This equilibrium is destroyed by the process of clearing and felling the jungle, and if a uniform population of susceptible hosts, in the shape of the plantation crop, then be planted on the cleared site, the result may be a spread of one or more root-disease fungi under peculiarly favourable conditions. Such troubles would not arise, of course, were the land laid down to non-susceptible annual crops for a period after clearing. This is apparently rarely practicable, however, and in the past the method adopted has generally been that of laboriously extracting as many as possible of the diseased roots and stumps of the jungle timber before planting the crop. Much of our knowledge of this sequence of events derives from recent work carried out at the Rubber Research Institute of Malaya [2]. In Malaya, the laborious process of clean clearing for the control of rubber root-rots is being replaced by a system in which infection is gradually eradicated in the first years of the growing crop. A tree-to-tree inspection of the collar and proximal parts of the roots is made at four-monthly intervals; where infection is discovered, it is traced back to the piece of infected jungle timber which was its original source; this is forthwith removed and destroyed, and the infected root appropriately treated or destroyed, according to its condition. In this elegant method of control, the plants themselves are used to indicate the site of infected timber lying in the soil, and much expensive labour in grubbing the whole of the planting site is thereby saved. Such a control method, of course, really comes under the heading of rogueing (*v.i.*).

Of very recent interest is a development in Nyasaland, due to Leach [8]. After the felling of the jungle in preparation for clearing a site for tea-planting, there is vigorous and widespread infection of the roots of certain species by the fungus *Armillaria mellea*. This fungus occurs only to a moderate extent on the roots of the living jungle, but its development seems to be greatly facilitated by the lowered resistance of the roots after felling. *A. mellea* is then later on responsible for much trouble in the young tea-plantations, which may suffer severely from its attack. The only control method previously known has been removal of the infected roots and stumps from the soil. Leach has now made the significant observation that if the jungle trees are ring-barked some time before felling, the roots are invaded not by *A. mellea*, but by certain other fungi, which are harmless in young tea-plantations. He has attributed the failure of *A. mellea* to infect the roots of ring-barked trees to its preference for roots with a normally high carbohydrate-content,

and considers that it may be unable to invade and parasitize those in which the carbohydrate-content has been seriously depleted by ring-barking. Such a restriction might be due, of course, to the competition of other organisms better able to infect such roots low in carbohydrate-content, rather than to absolute inability of *A. mellea* to colonize such a substrate.

Methods that Check Activity of the Fungus during the Parasitic Phase

(*a*) *Increasing host-resistance*.—In many diseases caused by root-infecting fungi, the plants affected may be growing under optimum soil conditions and in full vegetative vigour. In other cases, however, the plant may be predisposed to disease by some injurious factor in the soil environment, or its resistance may be lowered by some nutritional deficiency in the soil. When this is so, rectification of the environmental factor concerned will be found to control the disease. The serious root-rot of sugar-cane in Hawaii, the West Indies, and elsewhere [9], and the browning root-rot of cereals in Canada [10], both appear to be due in the first instance to a low phosphorus-nitrogen ratio in the soil, though the immediate cause of the trouble in each case is the fungus *Pythium arrhenomanes*. Both diseases can be controlled in the field by the application of phosphate. Again, a serious root-infection of cotton in the Sudan, which has caused much concern of recent years [11], is associated with a number of different fungi, but the predisposing cause seems to be the poor root-aeration in the very heavy soils on which the crop is grown. In conclusion, the need for further research work on the relation of host-resistance to the nutrition of the plant must be emphasized. Such knowledge as we have concerning manurial factors and the incidence of disease is concerned mainly with foliage diseases, such as potato blight, apple scab, and the rusts and mildews of cereals. In the case of root diseases, manurial treatments must operate directly upon the causal fungus as well as upon host-resistance, and the precise effect of such treatments upon the latter can therefore be evaluated only with difficulty.

(*b*) *Rogueing*.—The majority of the more specialized root-infecting fungi appear to spread underground not directly through the soil, but along the inside or outside of the underground organs of the host [4]. Spread from an affected plant to its neighbours, therefore, occurs in such cases only by root-contact; the removal of visibly affected plants, together with the greater part of their root-systems, might thus be expected to check the centrifugal progress of infection from scattered infection foci in the crop. This is not so simple a matter as might appear, however, owing to the great extent of the root-system, and the difficulty of recovering diseased portions of roots from the ground. Moreover, infection may have travelled underground along the root-network for a considerable distance beyond a visibly affected plant, and the removal of this alone will thus fail to check the outward progress of the fungus.

This is well illustrated by the fate of heroic efforts to check the rapid extension of Panama disease of bananas in Jamaica, which is described by Cousins and Sutherland [12] and by Wardlaw [13]. The progress

of the disease, first reported on the island in the year 1911, was considerably checked, though not definitely arrested, by early enforcement of drastic rogueing, whereby it was compulsory to uproot and destroy plants growing on an area of four square chains around every visibly wilted plant. With the more rapid extension of the disease after the year 1920, the four-square-chain-system of rogueing was replaced by a graduated system, as follows: first to third case, four square chains; fourth to fifth case, one square chain; and after the fifth case, half a square chain. Finally, in some parishes, the disease became so widespread as to necessitate the reduction of the quarantine area to the individual visibly diseased plant, and the eight apparently healthy ones surrounding it. This is referred to as the nine-root treatment. The failure of rogueing to do more than merely retard the extension of Panama disease in Jamaica must be attributed in large part to the spread of the causal organism, *Fusarium cubense*, by agencies other than the host-plant. For example, the transport of infected planting material to disease-free areas must have been frequently responsible for the appearance of the disease in fresh localities, whilst Wardlaw [13] considers that flood-waters may have played an important part in the natural dissemination of the parasite.

More satisfactory appears to be the state of affairs on Malayan rubber plantations, where the rogueing method is being established on a firm basis by a thorough investigation of the whole root-rot problem [2]. By means of the periodical tree-to-tree inspection (described above), guesswork is being eliminated, and a gradual eradication of all buried sources of infection assured.

Rogueing methods have so far found their chief application among the root diseases of plantation crops, where, indeed, there is often no other choice. With annual field crops, other methods, such as crop-rotation, are available and more economical, and rogueing has so far found little favour. An interesting study of the *Verticillium albo-atrum* wilt of potatoes has been published by McKay [14], who found that a considerable reduction in the percentage of infected tubers at harvest could be achieved by the 'three-plant method' of rogueing, whereby a visibly wilted plant was pulled together with its two immediate neighbours in the row. Infection by root-contact appeared to spread much more rapidly along than across rows; this was attributed by McKay, not so much to the greater distance apart of plants between than along rows, as to the fact that root-development and root-contact between the rows had been checked by frequent cultivations during the earlier part of the growing season.

(*c*) *Making soil conditions less favourable for the subterranean activity of the fungus.*—Certain root-diseases of crops show a well-marked distribution with soil type; some are found on acid soils, but not on alkaline soils, and vice versa; others are limited to soils of light texture, and others again found only on soils of heavy texture, and so on. It is thus possible to some extent to tabulate these different root-diseases according to soil type [4]. Amendment of soil conditions, in such a way as to hinder the activity of the parasite, thus suggests itself as an aid in the control of

disease. Whilst this is certainly more easily accomplished in glass-house cultivation [15], there is yet appreciable scope for application of this principle under ordinary field conditions.

Even with field crops, some control of soil temperature can sometimes be obtained by variation in the time of planting [16]; control of wheat bunt, for example, is assisted by early autumn or late spring sowing, since at soil temperatures of 20° C. and above the wheat seedlings germinate more quickly and may escape infection [17]. Again, Walker and Wellman [18] found that onion smut, due to *Urocystis cepulae*, did not occur in those parts of the United States in which the soil temperature at planting time exceeded 29° C.

Soil tilth and aeration can certainly be varied by tillage operations. Thus Griffiths [19] has recommended the compaction of light soils by implements and by the trampling of a flock of sheep as a valuable control measure for the take-all disease of wheat.

Effective control of certain diseases, viz. potato scab [20], cotton root-rot [21], and take-all of wheat [22], has been obtained by the application of organic manures. Such control has been attributed chiefly to the antagonistic action towards the parasite of the soil saprophytes, the activity of which is greatly increased by the addition of fermentable organic matter to the soil. Such antagonistic action, in all probability, not only hinders the parasitic activity of a root-infecting fungus during the growing-period of the crop, but also hastens its disappearance from the soil during the subsequent fallow period.

Certain of the root-infecting organisms are very sensitive to soil reaction. The control of potato scab by the application of inoculated sulphur, to bring about an acid soil reaction, and the control of club-root of crucifers by liming, are widely quoted examples of the effect of soil reaction. Whilst quite a number of soil-borne diseases have been found to be potentially controllable by adjustment of the soil reaction, such a measure is only practicable on the more lightly buffered soils.

Control of disease by soil amendment is only possible within the range of soil conditions permitting economic production of the crop. Many of the root-infecting fungi show a tolerance of different soil conditions almost as wide as that of their host-plants; others again, are most active under just those soil conditions optimum for crop production. Even where control of a disease by soil amendment is possible, however, it will frequently prove impracticable; it can rarely be economically feasible, for instance, to change appreciably the reaction of highly buffered soils.

Where soil amendment is not possible, it may still be feasible in some cases to restrict the production of the crop to soil types unfavourable to disease. This possibility applies more particularly to the case of permanent or plantation crops, where for obvious reasons soil conditions are less under the control of the grower than on land devoted to annual crops. Of especial interest in this connexion is the work of Reinking [23], who has demonstrated a clear relationship between the incidence of Panama disease of bananas and soil type; the disease was found to be most prevalent on the light-textured sandy soils. Such considerations

should be borne in mind by those taking up land for the cultivation of a tropical plantation crop. Indeed, it may well be in the field of prevention rather than in that of cure that the study of soil conditions and soil-borne fungus diseases will eventually find its most valuable application.

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THE DETERIORATION OF GRAPE-VINES IN SALINE SOILS

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WITH PLATES 6, 7

SALINE soils occupy a prominent position among the different soil types of Palestine. They are found in various parts of the country, either as small spots, or as larger isolated saline areas, which may form entire districts (e.g. the saline soils in the southern part of the Jordan Valley). The concentration of soluble salts in these soils varies, and may attain 10 per cent.

These lands are generally desolate and covered only with the wild vegetation characteristic of saline soils. Only a very small fraction of them is cultivated, and the returns from cultivation are very small. With the expansion of colonization, the settlers find soils affected by salinity and, whether from ignorance or by design, proceed to cultivate and utilize them for irrigated and non-irrigated crops. It is not surprising, therefore, that in several settlements the effects of soil salinity should have made themselves felt after a few years of such exploitation. As a result of the high concentration of the salts, and the unfavourable physical properties of saline soils, the great amount of work and effort expended in establishing and cultivating orchards, vegetable gardens, and alfalfa and clover fields is wasted, and the fruit of many years' labour is lost.

The concentration of the salts in the soil, in general, determines the fate of the plant; the extent of the damage depends also upon the composition of the salts. Very small quantities of soda, sometimes not exceeding some hundredths of one per cent., suffice to cause injury to crops that are particularly sensitive to this poisonous salt. For many plants, approximate limits of concentrations of salts in soils, above which the plants are seriously affected, have been established [1]. The trees and other plants that are especially sensitive to an excess of salts and occupy an important place in our agriculture are the grape-vine, the orange, the grape-fruit, and the banana [2].

The original low salinity of soils is frequently increased by the accumulation of salts when land is brought under irrigation; irrigation-water containing a high percentage of soluble salts and improper irrigation-methods combine to cause the soluble salts to rise from the lower to the upper soil layers. Plants, which are of normal development at the start when the salinity is low, begin to deteriorate as the salt-concentration is increased by irrigation. A phenomenon of this kind has been observed in the vineyards of Beth-Alpha. The vines were planted originally in soil that was but slightly saline, but after several years of irrigation the salinity increased, the plants suffered serious damage, and sometimes died. This case was investigated by the Chemistry Division and is briefly reported in this paper.

Soils.—The soil of the Beth-Alpha vineyards belongs to the type of heavy soils, and its water-holding capacity resembles that of heavy soils

in Palestine. The lime-content is rather low as compared with other heavy soils in the Yezreel Valley. The soil is fairly rich in plant-foods (Table 1).

TABLE 1. *Chemical and Mechanical Composition of Beth-Alpha Soil (per cent.*)*

Depth of layer cm.	Chemical Composition					Mechanical Composition				*Water-holding capacity*
	N	P_2O_5	K_2O	*Organic matter*	$CaCO_3$	*Coarse sand*	*Fine sand*	*Silt*	*Clay*	
0–30	0·10	0·31	0·46	1·94	6·0	4·32	39·82	23·39	32·47	63·1
60–90	0·12	0·32	0·56	1·59	8·6	2·28	23·43	18·32	55·97	69·3

* All the data presented in this paper are referred to oven-dry matter.

The soils are definitely saline, the degree of salinity varying from section to section, the percentage of water-soluble salts fluctuating between 0·07 and 0·48 (Table 2). Topography is also a contributory factor in salinification, e.g. the rain-water which percolates and courses down Mt. Gilboa deposits, at the foot, the soluble salts which it gathers

TABLE 2. *Water-soluble Salts and Chlorine in the Vineyard Soils (per cent.)*

CHASSELAS VINEYARD	*Depth of layer cm.*	*Total soluble salts*	Cl	NaCl *as per cent. of soluble salts*
Soil from affected vine No. 1	0–30	0·129	0·026	33·3
	30–60	0·077	0·014	29·4
	60–90	0·099	0·014	22·7
	90–120	0·101	0·019	31·1
Soil from deteriorating vine No. 3	0–30	0·461	0·068	24·3
	30–60	0·088	0·013	25·0
	60–90	0·105	0·011	16·8
	90–120	0·089	0·019	34·6
Soil from dead vine No. 6	0–30	0·366	0·073	32·4
	30–60	0·088	0·011	20·0
	60–90	0·077	0·011	22·9
	90–120	0·109	0·019	28·3
MUSCAT HAMBURG VINEYARD				
Soil from healthy vine No. 7	0–30	0·185	0·023	21·1
	30–60	0·070	0·011	25·4
	60–90	0·074	0·014	31·3
	90–120	0·102	0·024	39·1
Soil from heavily deteriorated vine No. 10	0–30	0·227	0·022	15·9
	30–60	0·109	0·018	26·5
	60–90	0·130	0·031	38·3
	90–120	0·152	0·041	43·5
Soil from dead vine No. 11	0–30	0·478	0·049	17·0
	30–60	0·117	0·012	17·1
	60–90	0·091	0·018	31·7
	90–120	0·133	0·031	38·3

on its way. During the summer, the salts tend to rise from the lower layers to the higher, where they accumulate in the intervals between irrigations.

The soil analyses of the affected sections show clearly that the percentage of salts is highest in the surface-layer and is considerably less in the layer below it. Common salt occupies a prominent position among the soluble salts. The data in Table 3 indicate an excess of sodium over

TABLE 3. *Chlorine and Sodium in the Soil Extract*

Soil from Vine	*Depth of layer cm.*	Cl %	Cl *m. eq. per 100 gm. soil*	Na %	Na *m. eq. per 100 gm. soil*
Heavily deteriorating, No. 10	0–30	0·022	0·62	0·021	0·91
Dead, No. 11 . .	0–30	0·049	1·38	0·032	1·39

chlorine. It therefore seems probable that all the chlorine served to form common salt. The figures for sodium chloride given in the tables are calculated from the chlorine-contents. That this salt shifts and accumulates in various degrees in the different layers is shown by the ratios of common salt to total salts.

The soils are of the white alkali type. They contained no trace of soda.

In Table 4 are given the analytical data for an unirrigated section of land adjacent to the affected area. This section contains little chlorine and the soluble salts typical of many other non-saline heavy soils.

TABLE 4. *Water-soluble Salts and Chlorine in Non-irrigated Soil (per cent.)*

Depth of layer cm.	*Total soluble salts*	Cl	NaCl *as % of soluble salts*
0–30	0·075	0·007	14·7
30–60	0·058	0·006	15·4
60–90	0·058	0·006	15·4
90–120	0·073	0·007	15·2

The Vines.—Two varieties of grape-vines were damaged by the salinity, Chasselas and Muscat Hamburg. The vineyard is nine years old and no sign of deterioration was observed before the ripening-season of 1934. The leaves were shed excessively; the growth and ripening of the grapes were interrupted, and they remained unusually small. When picking began, the majority of the affected vines shed their leaves, the branches dried up, and part or all of the fruit shrivelled (Plates 6, 7). The yield of fruit decreased considerably.

Analyses of the grapes from healthy and affected vines showed considerable differences in the content and composition of the soluble salts. The highest percentages of soluble salts and chlorine were found in the

heavily deteriorated Chasselas vines. Table 5 summarizes the results of analyses of the grapes from vines in different stages of deterioration. The fruit of slightly affected vines contained 1·98 per cent. soluble salts and that of very heavily deteriorated vines 6·68 per cent. The gradual rise in chlorine-content as deterioration increases is particularly evident: in fruit of slightly affected vines it constitutes 0·36 per cent., and in fruit of heavily deteriorated vines 1·50 per cent.

Analyses of the soil of the Chasselas vineyard indicate the relationship subsisting between the amount of soluble salts in the soil and the degree of deterioration of the fruit. The vines were damaged, apparently, by the salts which accumulated in the upper layer (Tables 2, 5).

In the Muscat Hamburg the relationship between the degree of deterioration and the accumulation of soluble salts in the fruit is not so obvious as in Chasselas (Table 5). But here too the connexion between

TABLE 5. *Water-soluble Salts and Chlorine in Deteriorating Grapes (per cent.)*

	Vine no.	*Condition of grapes*	*Weight of fruit gm.*	*Water-sol. salts*	Cl	NaCl *as % of sol. salts*
Chasselas	1	Affected slightly	1·54	1·98	0·36	30·0
,,	2	Affected	1·68	1·98	0·45	37·4
,,	3	Deteriorating	0·93	3·54	0·76	35·4
,,	4	Deteriorating heavily	0·69	4·47	1·18	43·5
,,	5	Deteriorating very heavily	0·46	6·68	1·50	37·0
,,	6	Dead	0·15	3·81	0·91	39·3
Muscat Hamburg	7	Healthy	2·22	3·05	0·09	4·9
,,	8	Deteriorating	1·68	1·98	0·29	24·1
,,	9	Deteriorating heavily	2·09	2·61	0·43	27·1
,,	10	Deteriorating very heavily	0·91	2·79	0·50	29·5
,,	11	Dead	0·56	1·22	0·24	32·9

the degree of deterioration and chlorine-content in the fruit is seen. Table 6 indicates the presence of an excess of sodium over chlorine in the fruit. The chlorine is probably bound to the sodium, i.e. the chloride in the fruit is common salt. The poisonous action of this salt on the vines is clearly apparent; whereas in healthy fruit the percentage of chlorine is only 0·09, in heavily deteriorated fruit it reaches 0·50. The ratio of common salt to total salts reaches 29·5 per cent. in heavily damaged fruit, and the lower the ratio, the less is the fruit damaged. In healthy fruit the percentage of total salts is high but the percentage ratio of common salt to total salts is only 4·9.

Fruit of dead vines, Chasselas and Muscat Hamburg, contains less soluble salts and chlorine than merely deteriorated fruit. The killed

TABLE 6. *The Chlorine and Sodium in Muscat Hamburg Grapes*

Vine no.	*Condition of vine*	Cl %	Cl *m. eq. per 100 gm.*	Na %	Na *m. eq. per 100 gm.*
8	Deteriorating	0·29	8·18	0·35	15·22
10	Deteriorating very heavily	0·50	14·10	0·58	25·22

vines apparently cease all activity and with it also absorption of salt from the soils. The percentage of common salt among the total soluble salts in the fruit of dead vines is considerable and reaches 39·3 in Chasselas and 32·9 in Muscat Hamburg.

Sugar and Acids in the Fruit.—The accumulation of salts in the fruit during its growth seriously interferes with the physiological processes. The salts which cause the drying of the leaves interfere with photosynthesis, affect the protoplast, and consequently impede also the process of sugar-formation. The percentage of sugar in slightly affected Chasselas is 70·2; in very heavily deteriorated fruit it falls to 31·1 (Table 7).

TABLE 7. *Glucose and Acids in Grapes (per cent.)*

	Vine no.	*Condition of grapes*	*Glucose*	*Acids calculated as tartaric acid*	*Ratio of glucose to acids*	*Moisture*
Chasselas grapes	1	Affected slightly	70·2	2·3	30·5	74·8
,,	2	Affected	70·6	2·5	28·2	75·7
,,	3	Deteriorating	43·6	3·1	14·1	82·8
,,	4	Deteriorating heavily	40·9	3·9	10·5	83·0
,,	5	Deteriorating very heavily	31·1	5·6	5·6	80·7
Muscat Hamburg grapes	7	Healthy	80·8	1·2	67·3	77·1
,,	8	Deteriorating	67·8	3·5	19·4	59·0
,,	9	Deteriorating heavily	56·9	3·7	15·4	72·4
,,	10	Deteriorating very heavily	46·0	3·6	12·8	73·8

The reverse is true of the acid-content of the fruit (Fig. 1): the percentage of acids rises gradually from 2·3 in slightly affected fruit to 5·6 in deteriorated fruit. The ratio of sugar to acid therefore falls from 30·5 in slightly affected fruit to 5·6 per cent in very heavily deteriorated fruit. Similar observations were made on the Muscat Hamburg grapes.

Soil Salinity and Leaf-composition.—The leaves, like the fruit, were seriously affected by the salinity of the soil: the tips turned yellow, and brown spots appeared all over the leaf-blade. As deterioration progressed, the drying of the leaves increased. On heavily deteriorated vines the leaves turned brown and dried out until they crumbled. The tips of the

shoots became shrunken; their colour turned from green to dark brown; and after some time they dried up completely and died, whilst the leaves were 'burnt' and shed, leaving the branches naked. The damage was caused mainly by the accumulation of large quantities of chlorides in the leaves. The percentage of chlorine, which is 0·04 in healthy leaves of a

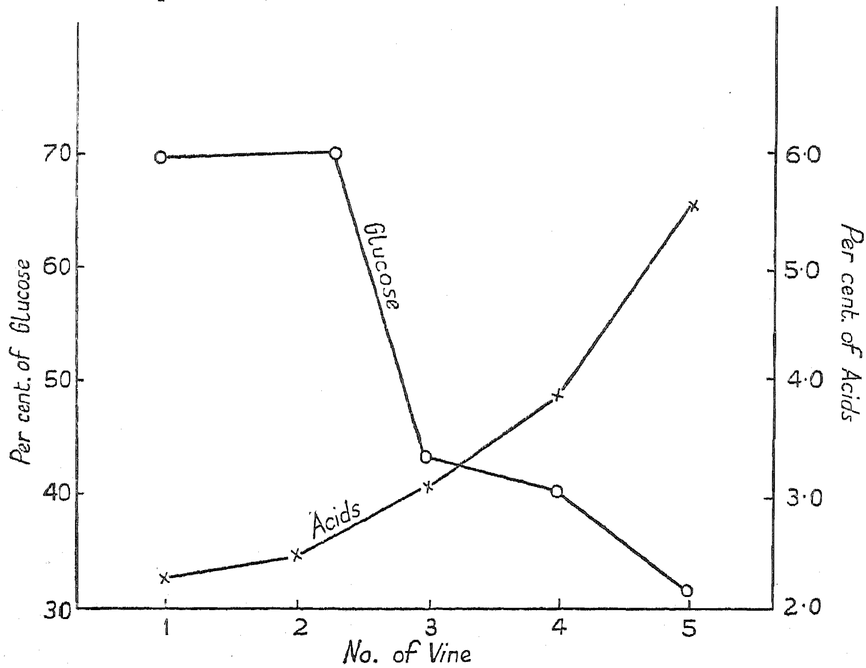


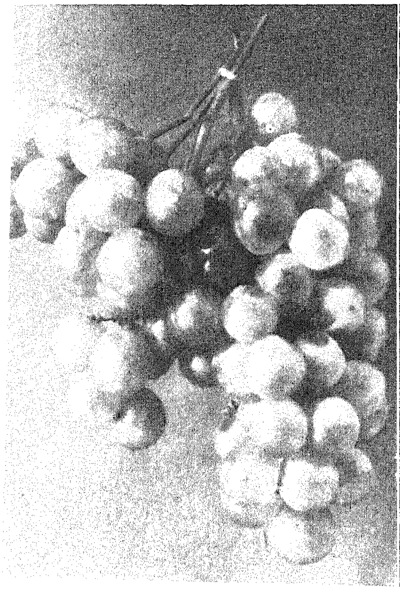
FIG. 1. Glucose and acids in Chasselas grapes affected by alkalinity.

Muscat Hamburg vine, reaches 1·50 in leaves of deteriorated vines, and 1·07 in leaves of dead vines. In Chasselas, the accumulation of chlorine is even more marked and reaches 3·84 per cent. in leaves of dead vines

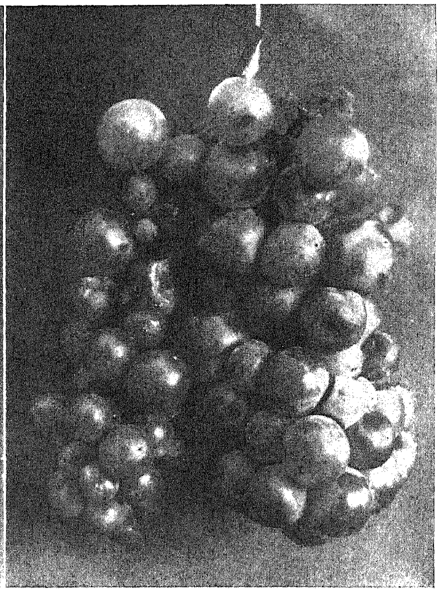
TABLE 8. *Ash- and Chlorine-Contents of Vine Leaves (per cent.)*

Vine	*Leaves from vine no.*	*Condition of vine*	*Ash*	Cl
Chasselas	1	Slightly affected	14·89	1·19
"	4	Deteriorating	17·71	3·35
"	6	Dead	15·01	3·84
Muscat Hamburg	7	Healthy	13·14	0·04
" "	9	Deteriorating	12·84	1·50
" "	11	Dead	9·06	1·07

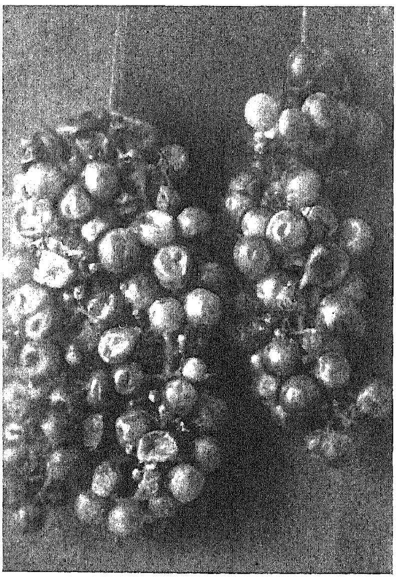
(Table 8). The proportion of chlorides to total salts increases with increasing deterioration, since the high concentration of salts in the soil of the affected sections does not increase the percentage of total salts in the leaves. On the contrary, the amount of salts is less in leaves most heavily affected. The same relationship was observed in the fruit of



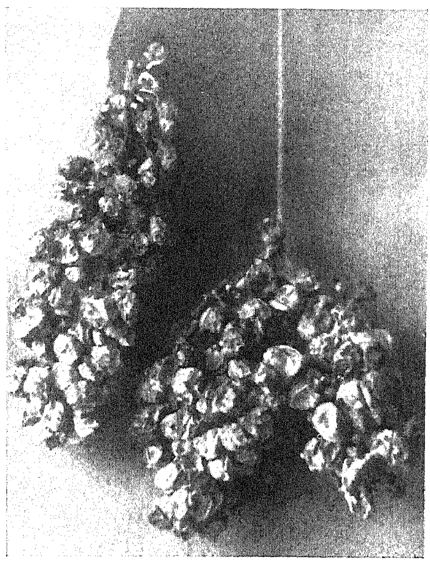
1. Bunch of slightly affected Chasselas grapes. Vine No. 1



2. Bunch of deteriorating Chasselas grapes. Vine No. 3



3. Bunch of heavily deteriorating Chasselas grapes. Vine No. 4



4. Bunch of shrunken Chasselas grapes. Vine No. 6

dead Chasselas and Muscat Hamburg vines. The excessive concentration of salts in the soil solution apparently damaged the roots of the plants concerned and thus interrupted the absorption of minerals from the soil. The damage to the roots did not, however, prevent the penetration of chlorides and their accumulation in the leaves in rather considerable amounts. It is noteworthy that the chlorine in the leaves is not held by sodium alone (as common salt), as it was in the juice of the fruit and in the soil solution, but is in part held also by other bases. Table 9 shows the excess of the chlorine over sodium in the affected leaves.

TABLE 9. *The Chlorine and Sodium in Leaves of Muscat Hamburg Vines*

Leaves from vine no.	*Condition of vine*	Cl %	Cl *m. eq. per 100 gm.*	Na %	Na *m. eq. per 100 gm.*
7	Healthy	0·04	1·13	0·098	4·26
8	Deteriorating	1·54	43·42	0·71	30·87
9	Deteriorating heavily	1·50	42·30	0·42	18·26
10	Deteriorating very heavily	1·00	28·20	0·43	18·70
11	Dead	1·07	30·17	0·72	31·30

Summary

The presence of high concentrations of chlorine, as sodium chloride, in the clay soil of Beth-Alpha vineyards, caused the vines, Chasselas and Muscat Hamburg, to deteriorate and to die.

The symptoms shown by the affected vines are described.

The chemical and mechanical composition of the soil is recorded; also the contents of water-soluble salts and chlorine in the irrigated and non-irrigated soil.

Analyses were made of the soluble salts, chlorine, glucose, and acids contained in the grapes; and of the ash-constituents, chlorine, and sodium contained in the leaves of the vines, in health, at different stages of deterioration, and at death.

The percentage of sodium chloride found in the grapes varied from 0·15 (healthy Muscat Hamburg) to 2·47 (heavily deteriorated Chasselas); that of chlorine in the leaves varied from 0·04 to 3·35, respectively.

In the fruit, the amount of glucose diminished and that of acids increased with progressive deterioration, the maxima recorded being 80·8 per cent. for glucose and 5·6 per cent. for acids.

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INVESTIGATIONS ON BLACK-ARM DISEASE OF COTTON UNDER FIELD CONDITIONS

II. THE EFFECT OF FLOODING INFECTIVE COTTON DEBRIS

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MASSEY [1, 2] has indicated that infective cotton debris on the ground can be inactivated by continuous and heavy flooding. In the first part of this paper is described an experiment, carried out on the Gezira Research Farm in 1933, to test the results of this treatment on a field plot; and in the second part the results obtained from a large-scale application of this treatment in the Gezira irrigated area in 1934 are set forth.

PT. I. THE EXPERIMENT ON THE GEZIRA RESEARCH FARM

The method employed was to lay infected cotton debris (exclusive of seed-cotton) on the ground, flood it for varying periods of time, and then sow disinfected cotton seed in this ground and note the amount of Black-Arm infection appearing on the cotton plants due to the infection from this debris carried by a rainstorm.

Lay-out.—A plot of 5 acres was divided into 32 sub-plots; each sub-plot was separated from its neighbours by belts of Pigeon Pea (*Cajanus indicus*) 10 m. thick, which, at the beginning of the experiment, had reached a height of 4–5 ft. The effective area of such sub-plot, i.e. exclusive of the belt, was 12 × 10 m.

Treatments. (1) Infected cotton debris flooded for four days.
(2) ,, ,, ,, ,, two ,,
(3) ,, ,, non-flooded (control).
(4) Two sowing-dates of the cotton, viz. July 26 and Aug. 16.

The treatments were randomized and replicated five times, and two sub-plots were left throughout *without debris*, to test (*a*) whether the seed itself was free from Black Arm, and (*b*) whether the screens were effective in preventing the spread of the Black-Arm organism from sub-plot to sub-plot.

Cotton debris.—Diseased cotton plants were collected in February, the green bolls and any seed were removed, and the stems, boll-cases, leaves, and petioles stored in sacks until required, the stems having previously been broken into pieces about 4–5 in. long. The seed (which was likely to produce infected seedlings) having been removed, any disease appearing in the experiment would come solely from the infected debris.

Cultural details.—On March 11, 1933, the diseased debris was measured out and spread on all sub-plots except two, the amount in each sub-plot being equal both in quantity and in kind.

The flooding of all sub-plots, except the control sub-plot, was carried out between July 16 and 20, the debris having been previously covered very lightly with earth, and the banks of each sub-plot raised sufficiently to allow the water to cover the tops of the ridges. While the sub-plots were flooded, a large proportion of the debris floated on the top of the water; no attempt was made to push this debris into the soil under the water.

The two sub-plots *without debris* were flooded for two days.

All seed (Egyptian Sakel) used in this experiment was de-linted in concentrated sulphuric acid, and then disinfected by steeping in alcoholic mercuric chloride (1 in 1,000) for 15 min., washed in distilled water, and subsequently dried before sowing.

The first sowing was made on July 26, no pre-watering being given to the sub-plots, as on this date they were sufficiently wet for sowing. The two sub-plots *without debris* were dressed, before sowing, with soil containing 12 lb. of chloride of lime per sub-plot, to disinfect the soil against *chance* infection.

The second sowing was made on August 16, the cotton of the first sowing having been pulled out on the previous day to avoid any possibility of disease spreading from the sub-plots of the first sowing-date to those of the second sowing-date. All sub-plots were given a light pre-watering, except the control sub-plots and the two non-debris sub-plots, which were lightly watered *after* sowing.

Rainfall.—From the time of laying of the debris on March 11, the rainfall on the plot was as follows (mm.):

April	drops
May	30·6 mm.
June	35·4
July, up to 26	62·0
July 28	18·5
Aug. 3	1·0
4	drops
5	0·5
6	16·0
8	3·8
9	2·5
12	1·3
14	drops
16	2·0
17	1·0
18	drops
20	18·5
21	drops
22	4·5
24	drops
25	0·5
26	drops
27	9·0
29	7·5
30	47·5
31	2·0
Total	117·6 mm.

Sept. 1	drops
2	drops
6	5·0 mm.
9	9·0
11	29·5
19	5·5
22	1·0
26	2·0
Total	52·0 mm.
Oct. 4	drops
7	20·0
8	4·0
18	drops
19	drops
24	drops
31	12:0
Total	36·0 mm.
Nov. 1	1·0

Results of the Experiment

First sowing.—Dates of inspection of the seedlings for Black-Arm disease and the results recorded are given below:

Date of inspection	*Period after sowing*	*Result*
1–2.8.33	6–7 days	No Black Arm
5–6.8.33	10–11 ,,	,, ,,
9.8.33	14 ,,	,, ,,
12.8.33	17 ,,	,, ,,
13.8.33	18 ,,	1 infected seedling in a control sub-plot
15.8.33	20 ,,	1 infected seedling in a 2-days' flooded sub-plot 4 infected seedlings in control sub-plot

No infection appeared in the two sub-plots *without debris*.

On Aug. 15 all seedlings were pulled out in preparation for the second sowing.

Second sowing.—Inspections of the cotton seedlings for disease were carried out as follows:

Date of inspection	*Result*
Aug. 27	No Black Arm
Aug. 29–30	2 infected seedlings in one 4-day flooding sub-plot. 2 infected seedlings in one control sub-plot; infection very slight and infected seedlings pulled out.

Result of Inspection on Sept. 9–10

After 4 days' flooding		*After 2 days' flooding*		*Control (no flooding)*	
Plot no.	*Infected plants, %*	*Plot no.*	*Infected plants, %*	*Plot no.*	*Infected plants, %*
2	0·0	1	0·1	4	8·0
9	0·6*	10	0·1	11	28·1
18	1·9*	12	0·7	17	41·1
20	0·0	19	0·6	25	20·5
26	0·0	27	0·6	28	35·7
Average	0·5		0·4		26·7

* All occurred in one small area of each sub-plot.

The severity of infection (i.e. the size and number of the lesions) was very much greater on the seedlings in the control sub-plots than on those in the flooded sub-plots. In the latter there was frequently only one small lesion per plant.

No infection appeared in the two sub-plots *without debris*, confirming what these results already indicate, viz. (*a*) that the seed-disinfection was adequate, and (*b*) that the belts had acted as a sufficient barrier to the spread from sub-plot to sub-plot.

On Aug. 9–10 the sub-plots contained the following numbers of plants:

4 days' flooding		*2 days' flooding*		*Control*	
No. of sub-plot	*No. of seedlings*	*No. of sub-plot*	*No. of seedlings*	*No. of sub-plot*	*No. of seedlings*
2	1,805	1	1,226	4	1,020
9	2,196	10	1,251	11	853
18	1,808	12	1,313	17	594
20	1,771	19	1,420	25	662
26	1,308	27	1,587	28	749
Total	8,888		6,797		3,878

A third and final examination was made on Sept. 24, when the following results were obtained:

Plot no.	*Period of flooding*	*Infected plants, %*	*Average percentage*
2	4 days	0·7	
9	,,	3·6*	
18	,,	6·2*	
20	,,	0·0	
26	,,	0·0	2·1
1	2 days	0·3	
10	,,	0·5	
12	,,	4·4	
19	,,	6·7	
27	,,	2·6	2·9
28	Control (no flooding)	89·7	
25	,, ,,	71·5	
17	,, ,,	90·0	
11	,, ,,	69·8	
4	,, ,,	26·5	69·5

* All occurred in one small area of each sub-plot

The degree of infection of individual plants remained as before: in the flooded sub-plots the lesions were lightly spotted over the leaves; in the controls they were much larger, and often ran down the veins.

Discussion

The results from the first sowing-date are inconclusive, very probably because the cotton plants had not been sufficiently long in the ground for the disease to develop.

The results of the second sowing, however, show conclusively the killing power of irrigation-water on the Black-Arm organism in the dried tissues of the cotton plant.

The presence of infection in *all* the 2-day flooded sub-plots, and in only two of the 4-day flooded (these two showed infection only in small areas that might have escaped the flooding), indicate that the killing of the organism is progressive and depends on the number of days the debris has been flooded.

The considerable variation of the amount of infection in the control sub-plots shows that the infectivity of the debris must have varied from sub-plot to sub-plot.

Another point of interest is that the normal rainfall which occurs before the sowing-date of the general crop, i.e. mid-August, is quite insufficient to inactivate all infective debris lying on the ground.

The smaller number of seedlings in the control sub-plots was due to the poor germination which frequently follows a sowing that is post-watered.

Pt. II. LARGE-SCALE TRIAL IN THE GEZIRA IRRIGATED SCHEME

The success of flooding as a control measure for Black-Arm infective cotton debris was so apparent that the Sudan Plantations Syndicate, Ltd., very kindly agreed to test the method on a large scale. In consequence, Hag Abdulla block, containing a total area of 4,102 acres of cotton-land, and also 1,136 acres of cotton-land in Seleimi block, were set aside for this trial.

In a previous paper [3] the author has fully described the lay-out of cotton-land in the Gezira Irrigation Scheme, to which reference must be made for a full explanation of any terms used here. It must suffice here to state that the land commanded by any particular canal is divided into 90-acre strips; each strip is called a 'Number', and its length lies in a direction at right angles to the canal. The Number is divided, parallel to the canal, into 9 tenancies of 10 acres, and each 10-acre plot is called a 'Howasha'. Each howasha is divided for watering purposes into 16 strips, each called an 'Angaia'; each angaia is parallel to the length of the number, and thus Angaia 1 will be that immediately alongside Angaia 16 of the adjacent Number. In the crop-rotation used in the Gezira, it very frequently happens that the cotton Number of the previous season lies immediately alongside that of the coming season's crop, and thus becomes a menace, from the Black-Arm point of view, to the new crop.

Design of the Experiment

In the *Hag Abdulla* area it was intended to use the cotton-land of an adjacent block, Ghubshan, as control, and to compare the intensity of Black-Arm infection in them. Unfortunately, continuous heavy rains seriously delayed the sowing in Ghubshan, and it was not possible to make a just comparison between the two areas. Hag Abdulla area was thus left without an adequate control.

In the *Seleimi* area suitable controls were available. The experiment here was carried out in a group of six parallel canals named 'Abu Senena', 'Dafalla', 'Falani', 'Seleimi', 'Idris', and 'Ali', and the area flooded was the 1933–4 cotton-land commanded by the three canals, Falani, Seleimi, Idris. The 1933–4 cotton-land of the three remaining canals (Abu Senena, Dafalla, and Ali) was *not* flooded and acted as a control area. The six canals were so situated that the land of Abu Senena

and Dafalla canals bounded the experimentally treated (i.e. flooded) area on the east, and the land of Ali canal bounded it on the west. Since these canals were all parallel, the direction of the 'blow' from old cotton-land to new would be the same in all canals.

Cultural Operations applicable to both Hag Abdulla and Seleimi

Beginning about the third week in April, the cotton plants of the 1933–4 season were pulled out by the tenants and burnt, the land cleaned as far as possible of debris on the ground, and each howasha divided by high banks into plots, four in Hag Abdulla and six in Seleimi.

The flooding of this 1933–4 cotton-land was then started; in both areas it lasted from about the third week in April to the second week in June, and the water covered the land for at least two days. As will be well realized, when attempting to flood by irrigation an area of this magnitude, certain high places would be bound to escape adequate flooding, and the debris on these places would be a potential source of danger to the coming crop.

As soon as the land was dry again, both areas were cleaned by the tenants (again, *as far as possible*) of any debris that had floated down and been retained by the sides of the banks. Most of the fallen cotton seed that germinated after the flooding soon died for lack of water.

The 1933–4 cotton-land of Ali, Dafalla, and Abu Senena canals (i.e. the non-flooded controls to the flooded area in Seleimi) was cleaned as far as possible of the debris remaining after the pulling-out of the cotton plants.

The above represents the treatment accorded to each area. The irrigation figures show that 5,698,000 cu.m. of water were used at Hag Abdulla, equivalent to 1,390 cu.m. per acre or 33 cm. over the area, and that 1,318,000 cu.m. of water, equivalent to 1,160 cu.m. per acre or 28 cm. over the area, was used in Seleimi. The sowing of the new cotton, using seed disinfected with Abavit B in both areas, was started at the beginning of August and finished by the first week in September.

Preliminary Survey of Flooded 1933–4 Cotton-land before Sowing of New Crop

Between July 15 and 31, 1934, an inspection was made in the following areas: (*a*) selected howashas in Hag Abdulla block, together with some howashas in the adjacent block (Ghubshan) as a possible control to Hag Abdulla; and (*b*) selected howashas in Seleimi flooded and non-flooded area. The results may be summarized as follows:

(*a*) *Hag Abdulla and Adjacent Block*

(1) *Cotton seedlings* germinated from fallen seed-cotton were present on most howashas of the flooded area, but the number was extremely small; in the adjacent block seedlings were plentiful, as the following figures, obtained on a sample representing 1/24th of the howasha, indicate:

(i) Hag Abdulla (flooded land)

Howasha	*Total seedlings*	*Black-Arm infected seedlings*
13 Malik G.	2	..
13 " A.	3	2
14 Bolein H	..	..
8 Mahil A.	..	..
8 Talib B.	3	3
5 Sukul West A.	5	4
15 Talib A.	1	..

(ii) Ghubshan (adjacent block, non-flooded land)

Howasha	*Total seedlings*	*Black-Arm infected seedlings*
7 Yousif A.	94	91
7 Shukkaba East I	260	43*
7 Sherif I	162	127
7 Yousif H.	402	347
7 Jack A	91	59
7 Sherif A.	246	219*

* On sample representing 1/96th of an howasha.

It is evident that the flooding had very greatly reduced the infected cotton seedlings available for infection of the new crop, but had not completely killed the Black-Arm organism.

(2) *Weeds.*—Considerable evidence was obtained that the flooding had killed the greater portion of weed-seeds lying on the howasha, so that the weed growth was limited and sparse.

(*b*) *Selimi* (flooded and non-flooded howashas)

(1) *Cotton seedlings.*—The following results were obtained on a similar sample to that taken in Hag Abdulla.

Flooded Area

Howasha	*Total seedlings*	*Black-Arm infected seedlings*
12 Idris A.	9	1
12 " C.	11	0
15 " I.	1	0
12 Seleimi E	31	9
12 " G	45	9
6 " D	14	3
15 Falani B	2	0
6 " A	5	3
15 Seleimi B	6	0
9 Idris A.	0	0

The effects of the flooding noted in Hag Abdulla are thus repeated in Seleimi, where controls were provided. It will be noticed that the quantity of seedlings is relatively high in 12 Seleimi E & G ('Seleimi' is the canal, '12' is the Number, and 'E' & 'G' are two howashas in this Number out of a total of nine), but it was clearly evident that the

cleaning and flooding in this Number was not up to the standard of the remainder of the flooded Numbers.

Non-flooded Area

Howasha	*Total seedlings*	*Black-Arm infected seedlings*
9 Ali A . . .	148	23
5 „ A . . .	42	14
15 Dafalla D . .	136	48
3 Abu Senena I .	214	16
9 Dafalla I . .	81	14
6 „ I . .	139	135
3 „ I . .	79	78

(2) *Weeds.*—In contrast to Hag Abdulla, the weed-growth on the flooded howashas was thick and extensive, but a striking difference was noted in the *type* of weed. In the flooded howashas the weed was almost exclusively 'Rihan' (*Ocimum basilicum*, L.) with some 'Molokhia' (*Corchorus* sp.), whilst on the non-flooded howashas, 'Tebr' (*Ipomoea cordofanus* T.) was the dominant weed. So striking was this difference that it was possible to decide which had been the flooded howashas by mere inspection of the weeds. It seems evident that the flooding had killed the Tebr seed, whilst the more resistant Rihan & Molokhia seed was able to survive.

Results of the Examination of the 1934–5 Season's Cotton for Black-Arm Disease

As soon as the new (i.e. 1934–5) season's cotton plants had reached a suitable age, examinations were made to note the outbreak and intensity of Black-Arm infection, in order to determine the effect, if any, of this flooding treatment.

In Hag Abdulla very severe Black-Arm disease was found in most parts of the northern area. In so far as this severe infection was found, the experiment must be considered to have failed, since the cleaning and flooding were done as well as was possible in practice on such a large area. In the absence of suitable controls one was, however, left completely in the dark as to the precise effect of the flooding, and it was impossible to decide whether or not the disease would have been more severe had the flooding not been given at all.

Owing to this uncertainty the whole of the observational staff were concentrated in the *Seleimi area*, where it was possible to make suitable comparisons between cotton growing opposite flooded and non-flooded howashas. The remainder of the paper will be devoted to the results obtained in that area.

In choosing pairs of howashas for comparison, the following criteria were used:

(*a*) Both howashas of a pair must be similarly placed as regards proximity to 1933–4 cotton-land, i.e. in one case, one howasha of the pair would be opposite *flooded* 1933–4 cotton-land and the other opposite *non*-flooded 1933–4 cotton-land, or, alternatively, *neither* of the two

howashas would be opposite 1933–4 cotton-land (i.e. they would both be opposite 1933–4 *fallow* land).

(*b*) The 1934–5 cotton plants in both howashas were to be of the same sowing-date.

This information was available in the records of the Gezira Research Farm, and the pairs of howashas for comparison were selected there without previous knowledge of any Black-Arm disease that might be present in them.

Four different methods of examination were adopted:

Method I.—It was noticed that heavily infected plants occurred in the new cotton isolated, and it was decided to count these and note any difference in quantity as between howashas opposite flooded and non-flooded land.

An infected plant was considered to be an 'isolated heavy infection' if it had severe petiole or stem lesions (this was always associated with heavy leaf-infection), whilst around this infected plant up to a radius of ten yards the cotton plants were only lightly infected.

The four angaias nearest the 1933–4 cotton-land in eighteen comparable pairs of howashas were examined in this way with the following results:

Total isolated heavily infected plants:

(*a*) opposite non-flooded land—158;
(*b*) opposite flooded land—21.

This examination occurred between the dates September 9–25, 1934.

Method II.—While the above examination was in progress, each of the four angaias was marked by visual observation on a 0 to 7 scale for total intensity of disease, with the following result:

Total Intensity Marks:

(*a*) for cotton opposite non-flooded land—126;
(*b*) „ „ flooded land—18.

Method III.—Between September 22 and October 1 the cotton plants of ten ridges, equally spaced, were examined throughout the howasha in 17 comparable pairs of howashas (i.e. comparable for sowing-date and proximity to 1933–4 cotton-land), one howasha of each pair being in the flooded area and one in the non-flooded.

In these ridges, counts were made of the total plants and total infected plants per angaia, percentages of infection were calculated, and the results recorded in graphs.

In the appended table, showing the percentage of infection per howasha, it will be seen that with one exception (pair No. 14) the average percentage of infection per howasha in the non-flooded area is never less than *twice* that in the flooded area, and in most cases it is very considerably more.

Fig. 1 (p. 214) shows some of the graphs obtained in illustration of these results. They, and other graphs not included here, show that infection in the plants opposite the non-flooded howashas is most severe on the side nearest the old cotton-land. This finding is in accordance with results obtained in previous seasons [3].

Percentage of Infection per Howasha

Pair No.	Mean sowing-date	Adjacent to *L.S's C.L.	Percentage of infected plants	
			Flooded Howashas	Non-flooded Howashas
5	Aug. 4	Yes	13·5	65·8
2	5	,,	31·9	72·8
9	7	,,	5·1	64·4
1	9	,,	4·1	34·2
12	August	,,	0·9	37·4
14	August	,,	11·4	21·2
3	10	,,	1·8	45·2
4	August	,,	3·7	59·9
8	August	,,	0·6	6·8
10	August	No	7·4	57·3
15	12	Yes	4·4	45·3
7	13	No	1·8	4·8
17	14	Yes	4·2	9·3
6	15	,,	0·7	18·8
11	August	,,	1·6	40·7
13	August	,,	0·5	5·9
16	August	,,	0·2	33·6
Average for 17 howashas			5·5	36·6

* Last season's (i.e. 1933–4) cotton-land.

In cotton opposite the flooded howashas, on the contrary, this concentration of the disease on one side of the howasha is notably absent, and there is a more or less even distribution *through* the howasha. It seems evident, therefore, that the flooding has eliminated the cause of this heavy localized concentration, leaving only such sources of infection as will produce an even 'scatter' through the howasha.

Method IV.—During the latter part of November, i.e. when the rains had ceased and no further spread of the disease was likely to occur, the intensity of Black-Arm infection in 15 comparable pairs of howashas was estimated per angaia by visual observation on a 'severity scale' of 0–7, and the results are illustrated in Fig. 2 (p. 215). These 15 pairs of howasha were chosen from the 17 pairs examined by the Method III (*v.s.*), and to avoid personal bias the author was assisted in this estimation by J. M. Craig, Esq., V.C., of the Barakat Seed Farm, Sudan Plantations Syndicate.

In every case the howasha opposite flooded land still showed less Black-Arm intensity than the one opposite non-flooded land, and a comparison of these results with those obtained in the same howasha in September by Method III shows in many cases that where a peak of infection occurred in the earlier inspection a similar peak of infection persists up to the latter date.

Discussion

The persistence of a lower level of infection in the cotton plants opposite the flooded old cotton-land proves that the flooding operations had reduced the potential Black-Arm infection of the new crop. The fact that, in the plants opposite the flooded howasha, the intensive

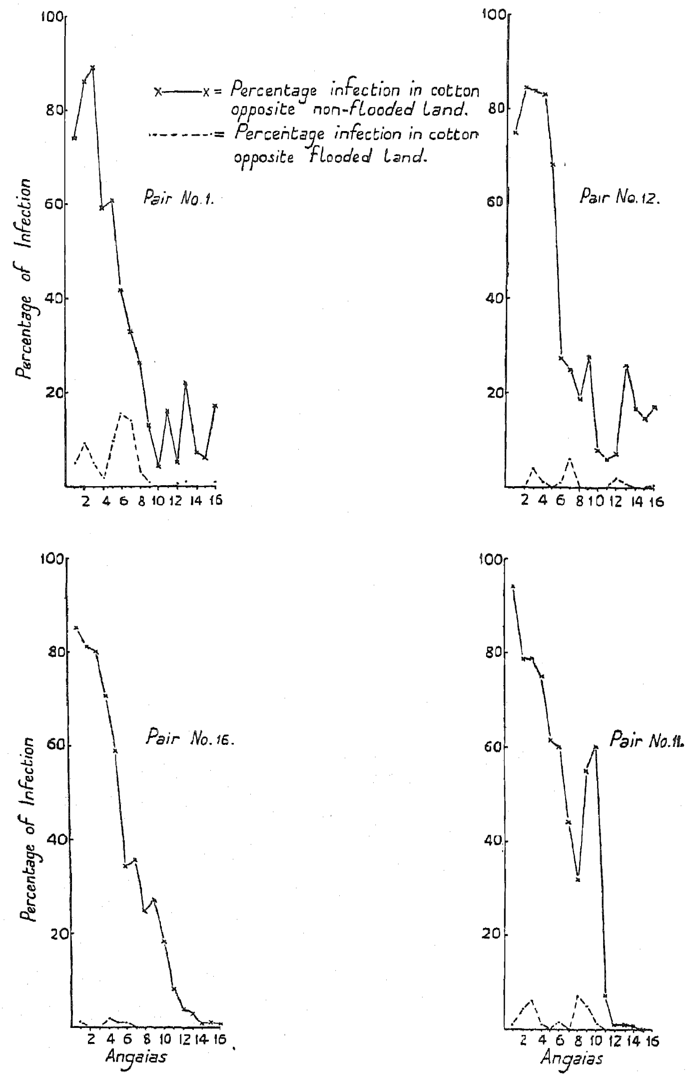

FIG. 1. Showing percentage of infection per angaia in comparable pairs of howashas (third method of examination between 22.9.34 and 1.10.34).

In all cases Angaia 1 is that nearest the previous season's cotton-land.

concentration of the disease on the side nearest the old cotton-land is markedly absent, clearly indicates that, as a result of this flooding, some very marked change was brought about in the mode of distribution of Black-Arm.

It would appear that the spread of Black Arm on to newly sown cotton occurs in two ways:

(*a*) A 'scatter' infection over the new cotton-land, before sowing, which

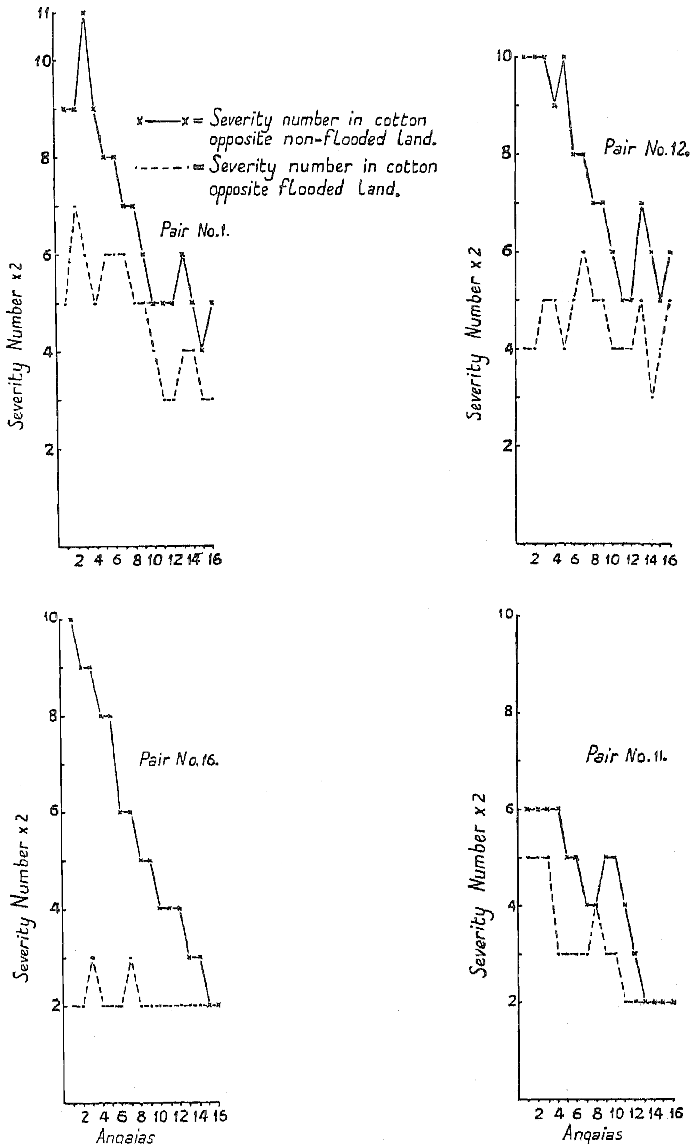

FIG. 2. Showing disease intensity as indicated by severity number per angaia in the *same* pairs of howashas as shown in Fig. 1 (fourth method of examination at end of November).

In all cases Angaia 1 is that nearest the previous season's cotton-land.

is believed to be due to portions of diseased twigs and pieces of seed-cotton blown on to the ground at the end of the previous cotton season.

(*b*) Direct infection from the old cotton-land after the new crop is up, resulting in a concentration of the disease on the side nearest this old cotton-land.

It would further appear that the 'scatter' method of infection is of general occurrence, but its effects are generally overlaid by the more intense 'direct' infection.

In Fig. 3 the mean severity of the disease in a howasha is plotted against the sowing-date of the cotton in that howasha. It shows clearly how rapidly the intensity of infection falls as the sowing-date becomes later, the rapidity of the fall being more pronounced in cotton opposite the flooded land.

Fig. 4 shows the percentage decrease of the disease due to the flooding in relation to the sowing-date. The effect of the flooding becomes very rapidly significant as the sowing-date approaches August 15.

The rainfall was practically the same in the flooded and non-flooded areas, and, therefore, the difference in intensity of Black-Arm infection in these two areas cannot be due to differential rainfall.

The quantity of the isolated heavily infected plants in the general cotton of the Gezira (not only in the experimental area) was considerably in excess of the number noted in previous years, and must be associated with a dissemination of infective material during a first attempt at cleaning the land after the cotton plants were pulled out; an attempt which was extended to the whole Gezira cotton area and not limited to the experimental area only.

The process of cleaning consisted of pulling out, collecting, and burning the cotton plants, clearing the land of large weeds, and then collecting from the ground the smaller cotton debris, which was heaped up and later burnt. Unless these heaps were burnt *immediately* it is clear that they would be exposed to the strong winds prevailing at that time of the year, and the material would be carried on to the surrounding cotton-land of the coming season.

It has already been mentioned that in the Seleimi experimental area both flooded and non-flooded howashas were cleaned as far as possible of debris lying on the ground. This work was done by the tenant, and the degree of cleanliness attained depended to a large extent on his keenness and industry. There would naturally be some variation in the amount still remaining on the various howashas at the time of the sowing of the new crop, and in no case was the land *completely* free of cotton debris, as might be attained on a small experimental plot.

As has already been indicated, a very important difference between the flooded and non-flooded land at the time immediately before sowing the new crop was the excess of infected volunteer cotton seedlings present on the latter; seedlings that had been germinated by the rains from fallen seed-cotton still remaining after the cleaning of the land (the remaining seed-cotton of the *flooded* land had been germinated by the flood and the bulk of the resultant seedlings had died through lack of water). It is reasonable to suppose that these infected seedlings are the cause of the heavy concentration of the disease on one side of the newly sown howasha. Later experimental work has confirmed the view that this intensive localized concentration is due to these infected volunteer seedlings. At sowing-time the old cotton-land is usually covered with weeds, which would tend to protect the new cotton from infective debris lying there;

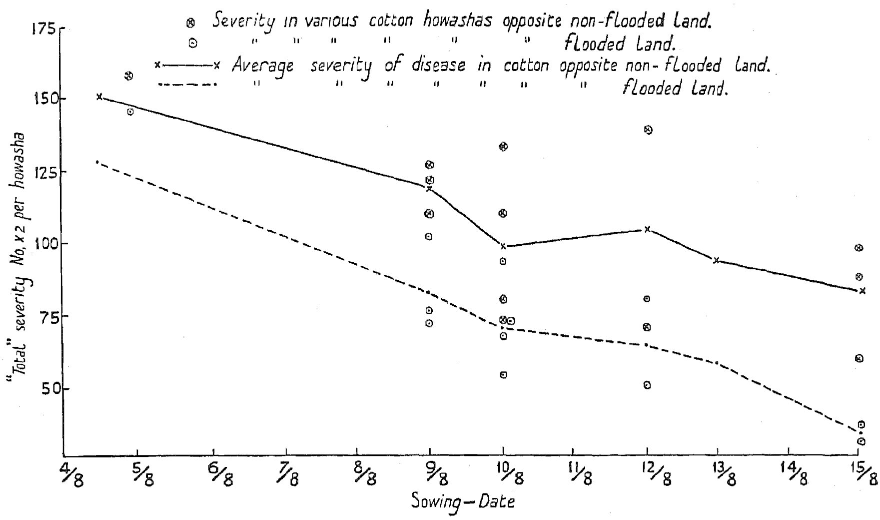

FIG. 3. Illustrating relation of severity of Black-Arm disease per howasha (as shown by sum of severity numbers per angaia) to sowing-date in cotton opposite flooded and non-flooded land.

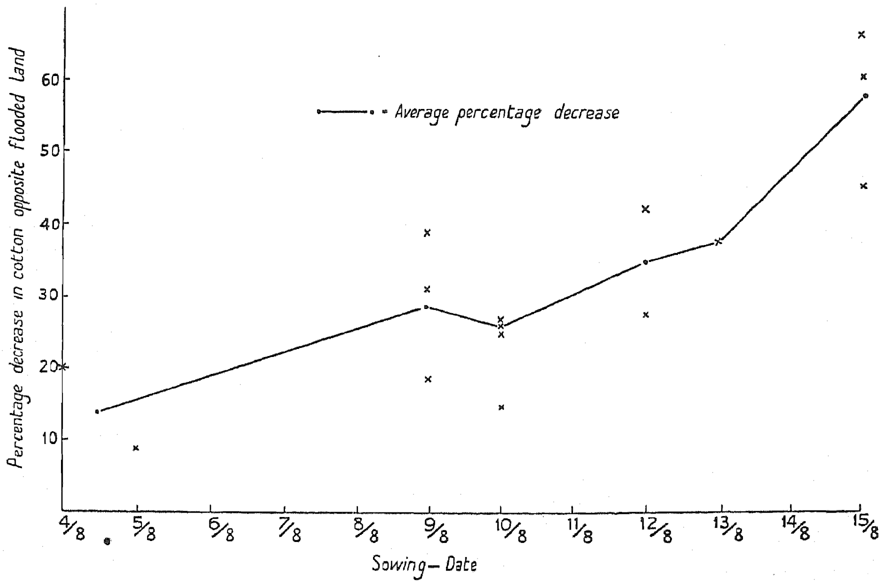

FIG. 4. Illustrating relation of sowing-date to percentage decrease per howasha of Black Arm in cotton opposite flooded land.

volunteer cotton *seedlings* would, however, be about the same height as the weeds, and the carry of the disease by a rainstorm from them to the new crop would be easy.

It has been impossible to put a monetary value on the increase in crop resulting from the milder Black-Arm attack consequent on the

flooding. On an area of this size great variation in soil fertility occurs, and the yield of the crop in any one howasha is intimately bound up with the good or bad farming of the tenant. In view of these varying factors it is impossible to say how much of the total crop was due to lack of severe disease. That the task of flooding and cleaning this area was one of considerable magnitude was evident very early in the proceedings; it was equally evident that it would be impracticable to make it a standard operation over the whole Gezira, even if a sufficiency of water was available during May and June.

Its application is, however, clearly indicated in localized areas of intense infection, where a combination of flooding of the old cotton-land and a later sowing of the new crop (i.e. after Aug. 15) could be employed with the reasonable hope of considerably reducing the disease.

Summary

1. A description is given of an experiment on the Gezira Research Farm where Black-Arm infected cotton debris was flooded for varying periods of time.

2. The results obtained show conclusively the killing-power of canal water on Black-Arm infected cotton debris on the ground.

3. The application of these flooding measures on a large scale to a portion of the irrigated cotton-land of the Gezira is then described.

4. The flooding of the old cotton-land has resulted in the absence of the usual concentration of the disease on the side of the new cotton howasha nearest this old land, and has left only a light scatter infection through the howasha.

5. Evidence is given for assuming that this localized concentration is due, in particular, to the carry by rainstorms of the infection from volunteer infected cotton seedlings appearing in the old cotton-land.

6. The final results obtained, though not, as might be expected, so striking as those described in Pt. I, are yet sufficiently conclusive to warrant the application of this control measure, combined with a later sowing-date, in small areas of intense infection.

Acknowledgements

I have to acknowledge my indebtedness to Mr. R. E. Massey, late head of the Plant Pathological Section, and Mr. M. A. Bailey, Director, Agricultural Research Service, Anglo-Egyptian Sudan Government, under whose direction these researches were carried out.

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STUDIES IN FIELD-PLOT TECHNIQUE WITH *P. TYPHOIDEUM* RICH.

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Introduction.—Fisher's method of analysis of variance [1] gave the agronomist a most efficient tool for increasing the precision of his field experiments. It enabled him to separate the total variation in its component parts. Soil variation is one of the most important and ubiquitous factors, and its effective elimination greatly improves the precision of an experiment, and, although it is universal, it does not occur in a uniform pattern. The lay-out, or 'local control', therefore, plays an important part in improving the precision of an experiment, in addition to the size and shape of a plot and the number of replications.

In Europe and America numerous uniformity trials have been conducted with a variety of agronomic crops. In India, with the increased understanding of Fisher's method, the value of preliminary trials has been recognized, and attempts are being made to standardize the methods of field experiments. In the Bombay Presidency the credit for popularizing the modern methods of field experiments is due to Dr. W. Burns, now Director of Agriculture, Poona. He originally suggested that uniformity trials with various crops be made at the different experimental farms in the Presidency to obtain information helpful in conducting proper field trials. The results obtained by Kulkarni and Bose will shortly be published. In this paper results of experiments conducted during 1933 and 1934 with bajari, *Pennisetum typhoideum* Rich., are reported.

Review of literature.—The literature dealing with field-plot technique is very extensive. Most of it, however, deals with old or obsolete methods. Therefore only a few recent investigations using analysis of variance will be reviewed.

Kirk [2], working with potatoes, found that a Latin-square lay-out gave a 27 per cent. lower probable error than a systematic arrangement. He found increased replication twice as efficient as larger sized plots. Justesen [3], and Kalamkar [4], found long narrow plots better than short, wide plots for potatoes. Both investigators advocate the use of smaller plots with larger number of replications. Reynolds *et al.* [5], working with cotton at two places, found small and long narrow plots better than large and short plots.

Lord [6], Mitra and Ganguli [7], and Pan [8] studied the suitable size and shape of plots for rice. For irrigated rice in Ceylon, Lord found 1/87 acre to be the best size, and a randomized arrangement more suitable than the Latin square. In Assam, Mitra and Ganguli obtained satis-

factory precision with 60 by 10 ft. plots with four replications. These investigators also found randomized blocks to be more practical than the Latin square. In China, Pan found single-row plots most efficient of all, except in one case where a two-row plot gave 9 per cent. more efficiency.

Studies by Immer [9] on sugar-beet show that four-row plots, with border-rows discarded, are most efficient. For sugar-cane, Vaidyanathan [10] found 1/20-acre plots with a ratio of length to width of 8 to 15 as the most suitable.

Kulkarni and Bose have found 1/80-acre plots to be more suitable for field experiments with sorghum. Investigations by Kadam and Kulkarni (unpublished) on wheat at Niphad, India, indicate smaller-sized plots to be more efficient than larger ones. The 1/80-acre plots, with 3 to 6 replications, were found most suitable to local conditions.

Material and methods.—The uniformity trials were conducted during the kharip seasons of 1933 and 1934 at the Cereal Breeding Station, Kundewadi, Niphad, in the district of Nasik. An acre of land in Survey Nos. 419 and 420 was drilled with the bajari strain 54 during the two years 1933 and 1934. In both places the field was previously cropped with wheat. The strain 54 is earlier by a week than the local bajari. The crop is sown in June or July after the arrival of the monsoon, and is generally harvested in the latter part of October or early in November. The strain 54 is poor-yielding, and the yields, 2·14 cwt. per acre in 1933 and 2·20 cwt. per acre in 1934, are average for the district.

Before harvesting, the fields were marked out in unit plots. After the removal of the five-feet border around the field, the plots were harvested and the crop tied in bundles and labelled. In due course the bundles were threshed by hand and the grain removed. The yields per plot are given in Appendixes I and II.

The data were analysed by the method of analysis of variance. The unit plots were combined to form plots of various shapes and sizes. In order to form blocks, to eliminate soil variance, four 'varieties' were assumed. The residue furnished a legitimate basis for the estimate of the error.

Experiments in 1933

The yield-figures of the 80 plots are given in Appendix I. The size of the unit plot is $16\frac{1}{2} \times 33$ ft. It was not possible always to utilize all the 80 plots in forming blocks. In such cases the first 16 plots on the south side were left out.

As an illustration, the analysis of variance of unit plots arranged in blocks from south to north is given in Table 1. In this case the last 16 plots on the south side could not be utilized. Hence, instead of 20, there are 16 blocks. Since the 4 varieties are dummy, their degrees of freedom merge with those within the blocks.

In judging the significance, the ratio of variance is used [11, 12]. Mahalanobis designates the ratio 'X', and Snedecor calls it 'F'. It will be seen that the variance between the blocks is seven times larger than that within the blocks. The theoretical value for $n_1 = 12$ and $n_2 = 45$

for 1 per cent. is 2·61. The observed value thus clearly exceeds the expected value. The blocks between themselves differ significantly.

TABLE 1. *Analysis of Variances of Unit Plots Arranged in Blocks from South to North, 1933*

	D.F.	*Sum of Squares*	*Variance*	*F*
Between blocks . .	15	10098·44	673·23	Observed, 7·05
Within blocks . .	48	4281·00	89·19	Theoretical 1 per cent., 2·61 for $n_1 = 12$, $n_2 = 45$
Total	63	14379·44	228·24	

In Table 2 standard errors, in percentage of the mean, are arranged according to the type of arrangement of the blocks. Under the table the various arrangements of plots and blocks are explained. The averages, for each size of plot, are also indicated.

It will be at once apparent that in the A type of arrangement, which consists of compact blocks, the errors are smaller than in either B or C type of blocks for a given size of plot. The exception is one half-guntha plot, where the C type of arrangement gives a low average error.

The average error of the 1-guntha plot in the A blocks is 10·8, whilst B and C types of blocks show average errors of 11·2 and 15·3 respectively.

In the 2-guntha plots of A blocks the variation in errors is from 7·6 to 8·9 with a mean of 8·5. The two plots in C blocks show very high errors. The error of the 2½-guntha plot in A block is 7·5, but the badly arranged block shows an error of 16·2 per cent. of the mean.

In the 4-guntha plots the errors are from 4·8 to 7·1, with an average of 6·2 in A blocks. The 5-guntha plots show the same average. The 4- and 5-guntha plots in the B and C blocks have very high errors. Thus in almost all cases the errors in A blocks are smaller than those in B and C blocks.

It will be seen further that in the A type of blocks the average errors diminish as the size of the plot increases. This is not the case in B and C blocks, where larger plots show larger errors than smaller plots in most of the cases.

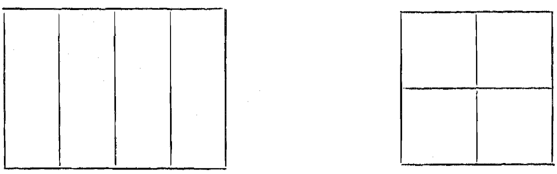
Considering the orientation and shape of the plots in the well arranged blocks, A, we find no definite tendency in any of the three plot arrangements. Similarly, shape of plots also does not exert any influence, except the unique case of the long narrow plot of 4 gunthas arranged in east to west direction. The plot has dimensions of 264×16½ ft., or a ratio of length to breadth of 8 to ½, and gives 4·8 error in per cent. of the mean.

A graphic illustration of the soil fertility is presented in Fig. 1. In constructing the contour lines the yields have been combined to form plots of 33 by 33 ft. It is assumed that the average yield of each plot is at its centre. The points at which the yields are 10, 20, 30 per cent. or more below or above the average are found by interpolation between the adjacent plots.

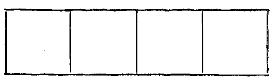
TABLE 2. *Standard Errors, in Percentage of the Mean, of Yields of Plots of Various Shapes and Sizes, 1933*

Plot size	*Well arranged blocks* (A)		*Poorly arranged blocks* (B)		*Badly arranged blocks* (C)	
½	$(1\times\frac{1}{2})^a$	14·1			$(1\times\frac{1}{2})^b$	13·3
	$(1\times\frac{1}{2})^c$	14·0				
	Mean	14·0				13·3
1	$(2\times\frac{1}{2})^a$	10·9	$(1\times 1)^a$	11·7	$(2\times\frac{1}{2})^b$	20·6
	$(1\times 1)^c$	10·8	$(1\times 1)^b$	10·8	$(2\times\frac{1}{2})^c$	10·0
	Mean	10·8		11·2		15·3
2	$(2\times 1)^a$	8·9			$(2\times 1)^b$	19·4
	$(4\times\frac{1}{2})^a$	8·9			$(4\times\frac{1}{2})^c$	20·0
	$(1\times 2)^b$	8·2				
	$(1\times 2)^c$	8·7				
	$(2\times 1)^c$	7·6				
	Mean	8·5				19·7
2½	$(5\times\frac{1}{2})^a$	7·5			$(5\times\frac{1}{2})^c$	16·2
	Mean	7·5				16·2
4	$(4\times 1)^a$	7·1	$(2\times 2)^b$	18·6	$(4\times 1)^c$	18·7
	$(8\times\frac{1}{2})^a$	4·8				
	$(1\times 4)^b$	6·0				
	$(2\times 2)^c$	7·0				
	Mean	6·2		18·6		18·7
5	$(5\times 1)^a$	6·4			$(5\times 1)^c$	15·4
	$(10\times\frac{1}{2})^a$	6·1				
	Mean	6·2				15·4

(A) i.e. the most compact form for a given shape and orientation of plot, e.g.



(B) i.e. the following arrangement of square plots:



(C) i.e. arrangements of the following type:

NOTE: The figures in brackets indicate the dimensions of the plots in half gunthas, the length from north to south being given first. The indices indicate the arrangement of the plots in blocks, a indicating that the 4 plots of a block run from west to east, b that they run from north to south, and c that they form a 2×2 pattern.

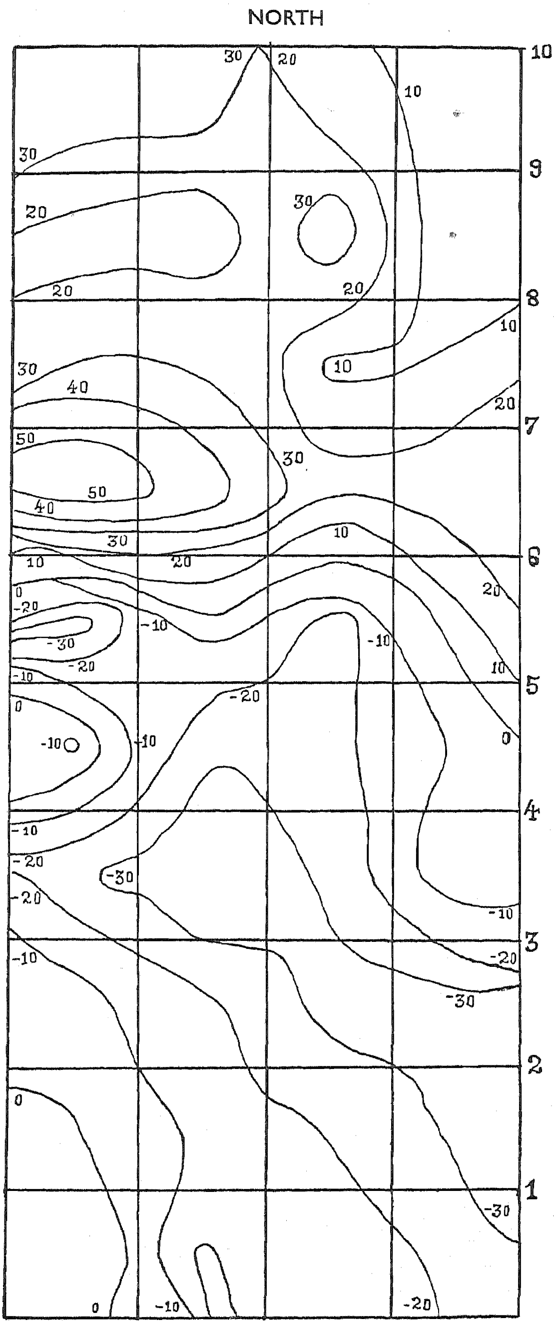


FIG. 1. Contour map of uniformity trial plot of bajari, 1933.

The soil map shows that the fertility increases gradually from south to north. The zero line passes through block 6. The general fertility lay-out is such that blocks in the same direction would show greater soil variability within themselves. This is indeed the case when length of plots arranged from south to north increases from 33 to 66 ft. It was found that plots 33 ft. long showed considerably smaller errors. This indicates that smaller-sized plots enable formation of blocks which are more homogeneous than those formed by larger ones.

Amount of information.—The amount of information per unit area is calculated from 1 / (area × variance).

The average errors for each plot-size, as shown in Table 2, are taken. The data are summarized in Table 3.

TABLE 3. *Amount of Information for Various Plot-Sizes in Well (A), Poorly (B), and Badly (C) Arranged Blocks, 1933*

Size of plot in gunthas	*Block-arrangement**		
	A	B	C
½	1·02	..	1·13
1	0·86	0·80	0·43
2	0·69	..	0·13
2½	0·71	..	0·15
4	0·65	0·07	0·07
5	0·52	..	0·08

* For explanation see under Table 2.

It will be seen that smaller plots furnish more information per unit area than the larger ones. The amount of information decreases as the size of the plot increases. In the well arranged blocks, A, the fall is gradual, whereas in the C type of blocks the decrease is drastic as the size of plot increases.

It will be noted further that plots of any given size in the well arranged blocks are much more efficient than the corresponding plots in either the poorly or badly arranged blocks.

The long narrow plot of 4 gunthas (264 × 16½ ft.), which showed an error of 4·8 per cent. of the mean, gives 1·08 information, indicating that in certain exceptional cases large plots may be as efficient as smaller plots.

Experiments in 1934

An acre of bajari crop in field No. 420 was cut in ¼-guntha plots (16½ × 16½ ft.) in this year. There were 160 plots. The unit plot was, therefore, one-half as small as in the previous year. The analysis of the data was done as before.

The standard errors, in percentage of the mean, of various shapes and sizes of plots are summarized in Table 4. The errors are arranged according to the arrangement of the blocks.

Comparing the different block-arrangements first, it is seen that the

TABLE 4. *Standard Errors, in Percentage of the Mean, of Yields of Plots of Various Shapes and Sizes, 1934*

Plot size	*Well arranged blocks* (A)*		*Poorly arranged blocks* (B)*		*Badly arranged blocks* (C)*	
$\frac{1}{4}$	$(\frac{1}{2}\times\frac{1}{2})^c$	7·6	$(\frac{1}{2}\times\frac{1}{2})^a$	8·5		
			$(\frac{1}{2}\times\frac{1}{2})^b$	6·4		
	Mean	7·6		7·4		
$\frac{1}{2}$	$(\frac{1}{2}\times 1)^b$	8·9			$(\frac{1}{2}\times 1)^a$	10·6
	$(\frac{1}{2}\times 1)^c$	10·0			$(1\times\frac{1}{2})^b$	10·0
	$(1\times\frac{1}{2})^a$	10·4				
	$(1\times\frac{1}{2})^c$	9·3				
	Mean	9·6				10·3
1	$(1\times 1)^c$	8·1	$(1\times 1)^a$	9·5	$(\frac{1}{2}\times 2)^c$	8·8
	$(\frac{1}{2}\times 2)^b$	7·2	$(1\times 1)^b$	8·5	$(2\times\frac{1}{2})^b$	11·6
	$(2\times\frac{1}{2})^a$	9·1			$(2\times\frac{1}{2})^c$	9·8
	Mean	8·1		9·0		10·1
2	$(2\times 1)^a$	8·8			$(2\times 1)^b$	10·2
	$(2\times 1)^c$	8·5			$(4\times\frac{1}{2})^c$	10·2
	$(\frac{1}{2}\times 4)^b$	6·6				
	$(1\times 2)^b$	6·7				
	$(1\times 2)^c$	7·5				
	$(4\times\frac{1}{2})^a$	8·4				
	Mean	7·7				10·2
$2\frac{1}{2}$	$(2\frac{1}{2}\times 1)^a$	8·3			$(2\frac{1}{2}\times 1)^b$	10·4
	$(5\times\frac{1}{2})^a$	6·9			$(2\frac{1}{2}\times 1)^c$	9·8
					$(5\times\frac{1}{2})^c$	7·6
	Mean	7·6				9·3
4	$(8\times\frac{1}{2})^a$	7·8	$(2\times 2)^b$	9·5	$(4\times 1)^c$	9·9
	$(1\times 4)^b$	5·3				
	$(4\times 1)^a$	7·4				
	$(2\times 2)^c$	6·8				
	Mean	6·8		9·5		9·9
5	$(10\times\frac{1}{2})^a$	5·8			$(5\times 1)^c$	7·0
	$(5\times 1)^a$	5·8			$(2\frac{1}{2}\times 2)^b$	9·1
	$(2\frac{1}{2}\times 2)^c$	8·2				
	Mean	6·6				8·0

* For explanation see under Table 2.

errors in the well arranged blocks, are, as a whole, smaller than in the poorly or badly arranged blocks.

The errors of $\frac{1}{4}$-guntha plots in either well arranged or in poorly arranged blocks do not show much difference. It will be noted, however, that plots arranged from north to south show the least error in the B type of arrangement; but an arrangement in the east to west direction increases the standard error.

The errors of $\frac{1}{2}$-guntha plots in A blocks vary from 8·9 to 10·4, whilst

the plots in C blocks show 10·0 to 10·6 per cent. errors. The average errors in the two types of blocks are 9·6 and 10·3 per cent. of the mean respectively.

It will be noted that plots arranged from north to south in the A type of blocks give the smallest error.

All the three types of block-arrangement occur with the 1-guntha size. Here, again, we find that compact blocks (A) show smaller errors than the other two types. Among the well arranged blocks, plots from north to south again give the lowest error.

In the 2-guntha plots the variation in errors in the A type of block-arrangement is from 6·6 to 8·8 and the average error of all plots is 7·7 per cent. of the mean. Both the plots in the C type of arrangement show 10·2 error. It will be observed again that the plots from north to south show the least errors in the A type of blocks, there being practically no difference between the two shapes.

The other sized plots are not of agronomic importance, and hence it is not necessary to consider them in detail. It may, however, be pointed out that they exhibit trends similar to those in the smaller plots.

In this year's experiment also the errors in the well arranged blocks diminish as the size of the plot increases, but in the poorly and badly arranged blocks the errors either increase or are more or less the same.

In the well arranged blocks no influence of any particular shape of plot is apparent, but, as has been observed above, plots arranged from north to south do show consistent reduction in error.

Amount of information.—The amount of information contributed by the plots of various sizes is shown in Table 5. Only the average information for each size in the various types of block-arrangement is indicated.

TABLE 5. *Amount of Information for Various Plot-sizes in Well, Poorly, and Badly Arranged Blocks, 1934*

Size of Plot in gunthas	*Block-arrangement**		
	A	B	C
$\frac{1}{4}$	7·10	7·70	..
$\frac{1}{2}$	2·20	..	1·90
1	1·50	1·20	0·98
2	0·85	..	0·48
$2\frac{1}{2}$	0·69	..	0·46
4	0·54	0·28	0·25
5	0·46	..	0·31

* For explanation see under Table 2.

It will be seen that except for the $\frac{1}{4}$-guntha size the A type, i.e. compact arrangement, gives higher amount of information than the other arrangements. In the B type of blocks there were two arrangements of plots, one from east to west and another from north to south. The former showed 8·5 per cent. error, and the latter 6·4 per cent. Thus the average error of the B type of blocks for $\frac{1}{4}$-guntha size was brought down, and consequently the precision increased.

The smaller plots give more information than the larger ones, which show progressive decline. In other words, smaller plots, which enable more replications, are more efficient than the larger ones.

The general conclusion to be drawn from the results in 1934 is that the arrangement of plots from north to south in compact blocks is better than other arrangements.

The various sizes of plots in the different types of blocks are illustrated in Fig. 2.

Discussion

The results in the two years, 1933 and 1934, are in general agreement. The various sized plots in Survey No. 419, studied in 1933, show higher average standard errors than the corresponding plots in Survey No. 420. The former is therefore more variable in fertility than the latter. In both fields, as the size of the plot increased, reduction in errors was observed in the well arranged blocks. But the reverse was the trend in poorly and badly arranged blocks.

Although smaller plots have larger errors, they gave more information per unit area than the larger plots, indicating that the reduction in error in larger plots was not in proportion. There is a gradual decline in the amount of information in the well arranged blocks, whilst efficiency decreases rapidly in poorly and badly arranged blocks. In other words, precision in larger sized plots of the properly arranged blocks increases to a certain extent, but is virtually absent in improperly arranged blocks.

In the Survey No. 419 no definite orientation of plot was observed to give more precision, but in Survey No. 420 plots from north to south in compact blocks were more efficient than the plots arranged in other ways. Thus in certain cases definite placement of plots is helpful in increasing precision of the experiment.

Smaller plots are desirable for field trials as they are not only more efficient but are also more economic. The $\frac{1}{4}$- and $\frac{1}{2}$-guntha plots are most efficient. For agricultural operations $\frac{1}{4}$-guntha is unsuitable, as it is too small. With such very small plots difficulties arise when planting has to be done with the help of bullocks, as is usual in India. The $\frac{1}{2}$-guntha size, however, can be conveniently used.

An exceptional case of a long narrow plot, $264 \times 16\frac{1}{2}$ ft., running from west to east, was found in 1933. This plot showed a much smaller error and consequently very high precision. Thus in certain cases larger plots can also be used efficiently for field trials.

Summary

1. The experiments were conducted during the seasons of 1933 and 1934 with bajari, *P. typhoideum* Rich., at the Cereal Breeding Station, Kundewadi, Niphad, India. In 1933 the area was cut in units of $\frac{1}{2}$-guntha with dimensions of $16\frac{1}{2} \times 33$ ft. The next year the unit was $\frac{1}{4}$-guntha, or $16\frac{1}{2} \times 16\frac{1}{2}$ ft.

2. As the size of plot increased, standard errors, expressed in the percentage of the mean, diminished in the well arranged blocks, but in poorly and badly arranged blocks the reverse was the trend.

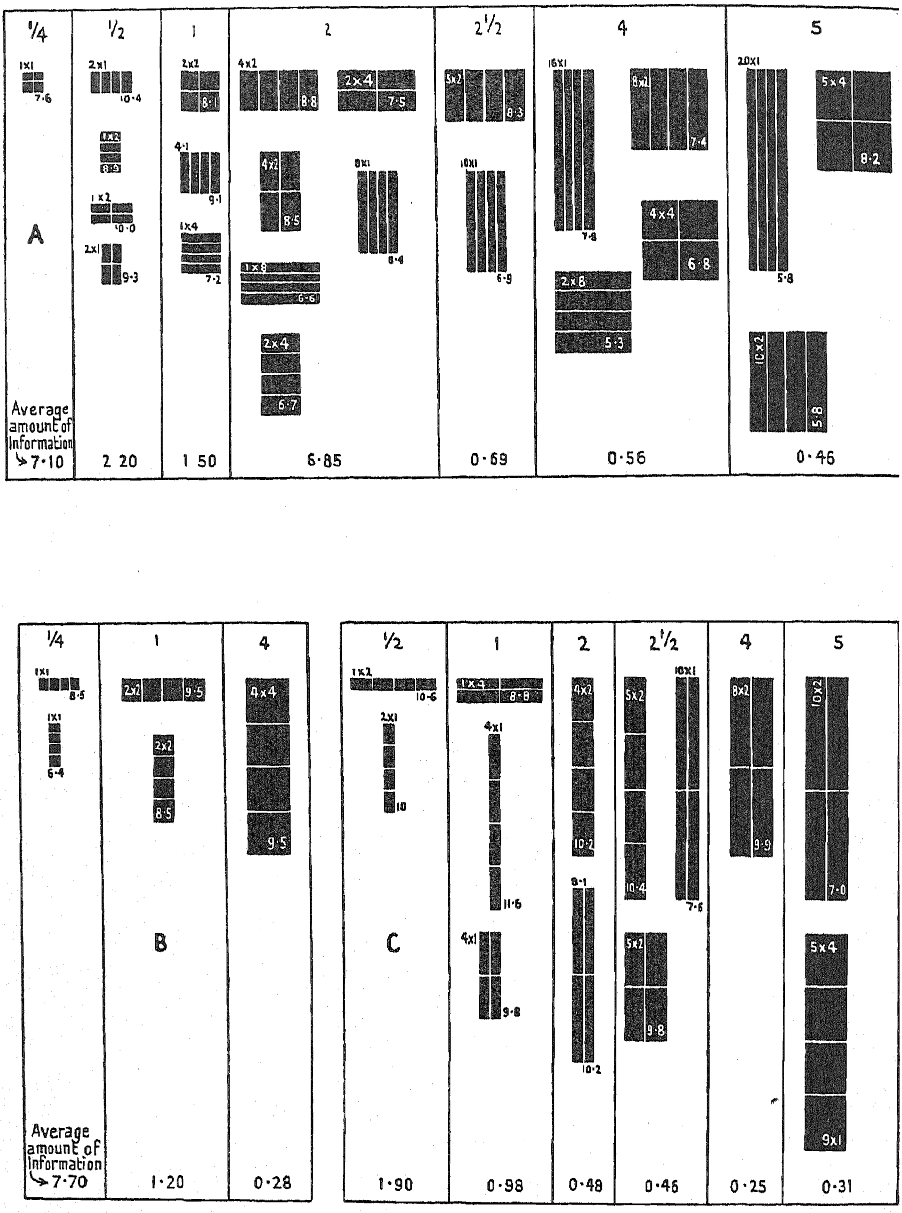


Fig. 2. Shape and size of plots in well arranged (A), poorly arranged (B), and badly arranged blocks (C), 1934. In the upper left-hand corner the dimensions of the plot are given in units of 16½ feet; the lower right-hand corner shows standard errors in percentage of the mean.

3. Smaller plots gave more information per unit area than larger ones. There was only one exception in which a plot of 4 gunthas ($264 \times 16\frac{1}{2}$ ft.) was very efficient. Plots in the well arranged blocks were more efficient than the corresponding sizes in poorly and badly arranged blocks.

4. In the 1934 experiments, plots arranged from north to south in well arranged blocks were observed to have lower errors than plots placed in other ways.

5. For field experiments $\frac{1}{2}$-guntha plots are more suitable than $\frac{1}{4}$-guntha.

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APPENDIX I.

Yield of Unit Plots in Ounces (1933)

NORTH

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	93	81	84	91	88	66	66	78
2	96	62	75	76	90	88	68	66
3	92	77	87	84	70	77	67	85
4	112	89	97	87	85	77	83	85
5	46	60	74	62	53	62	76	71
6	82	66	58	52	61	53	64	67
7	42	68	56	44	51	61	78	61
8	69	64	65	53	55	50	48	56
*9	76	62	66	61	56	61	55	52
10	92	60	65	53	66	62	58	53

* Plots left out from certain combinations.

APPENDIX II.

Yield of Unit Plots in Ounces (1934)

NORTH

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	48·4	41·6	54·0	47·6	51·6	42·4	48·4	52·8
2	44·8	46·0	55·2	45·6	48·4	39·6	44·4	56·0
3	44·4	34·4	46·0	48·0	40·0	36·4	38·8	52·8
4	48·8	42·8	44·4	40·4	41·2	39·6	41·6	54·0
5	50·4	38·4	45·6	44·0	32·4	42·4	41·6	44·0
6	48·4	43·2	44·4	44·4	39·2	33·6	36·4	42·0
7	59·6	53·6	50·8	42·4	39·2	36·8	43·6	43·2
8	59·6	45·2	38·4	38·8	33·6	38·8	36·8	44·8
9	43·6	41·2	38·0	37·6	37·6	34·0	36·0	41·2
10	54·4	43·6	34·8	43·6	39·2	36·0	43·2	48·0
11	42·4	42·4	44·8	39·6	39·2	30·8	35·2	46·8
12	44·4	32·8	36·8	44·8	27·2	27·2	37·6	39·2
13	33·6	42·0	34·8	41·2	32·0	38·4	35·2	43·6
14	38·4	35·2	33·6	36·4	34·4	30·8	34·8	39·6
15	34·0	41·2	41·6	32·8	31·2	38·8	41·2	43·2
16	37·6	49·6	36·8	40·4	37·2	36·8	36·4	40·8
*17	43·2	40·0	40·0	40·8	42·4	37·6	44·8	45·6
18	40·8	40·8	48·0	45·6	58·8	50·0	48·4	52·8
19	33·2	29·2	40·4	40·0	41·2	46·4	46·8	44·0
20	48·0	46·8	41·6	46·8	50·8	55·2	50·8	38·8

* Plots left out from certain combinations.

SWEET POTATO EXPERIMENTS

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THE sweet potato (*Ipomea batatas*) is an important crop throughout the tropics and particularly in the West Indies. It has been experimented with for some time past at the Imperial College of Tropical Agriculture, by post-graduate students who have recorded the results in dissertations which they submit in part requirement for the Associateship of the College. The experiments fall naturally into three groups—varietal, cultural, and manurial.

The College soil is a detrital sandy loam, somewhat reworked by stream-action, derived from quartz-schists which comprise the main rocks of the Northern Range of Trinidad. Its content of coarse and fine sand is about 50 per cent.; it is slightly alkaline in reaction, and contains only about 1·5 per cent. of organic matter in the surface 6-inch layer. Available potash is notably deficient (35 p.p.m. K_2O) and available phosphate slightly deficient (30 p.p.m. P_2O_5).

Varietal Experiments

Although all the cultivated varieties of sweet potato belong to one species, there are wide variations in habit, colour of skin, colour of flesh, and consistency. As is usual with vegetatively propagated crops, a very large number of differently named varieties are found, many of which are in all probability identical [1]. The local names generally allude to physical characteristics, e.g. 'Turkey Claw', or to the individual with whom the variety is associated in a particular area, such as 'Sealy'.

A preliminary trial of a dozen varieties was made in 1926–7. By 1930–1 these had been reduced to six, and the adoption of a modern lay-out gave definite significance to the results:

1930–1

Variety	*Yield (tons per acre)*	*Per cent. of 'Table' tubers*
Jackson	2·04 ±0·17	70
Black Rock	2·01 ,,	69
Black Sam	1·57 ,,	66
Red Nut	1·22 ,,	63
Sealy	0·89 ,,	75
Yellow New Jersey	0·80 ,,	53

The first three were superior to the last two at the 5 per cent. point; the first two were superior to the last three at the 1 per cent. point.

The cultivation of three of these varieties was continued to the next year along with one newly introduced one:

1931–2

Variety	Yield (tons per acre)	Per cent. of 'Table' tubers
Black Rock	4·72 ±0·30	68·1
Red Nut	2·85 ,,	71·2
Jackson	2·24 ,,	65·3
Purple Vine	1·42 ,,	52·5

The first was superior to all the others at the 1 per cent. point; the second was better than the fourth at the 5 per cent. point.

Another trial in the same season gave the following result, which was significant at the 1 per cent. point:

1931–2

Variety	Yield (tons per acre)	Per cent. of 'Table' tubers
Black Rock	4·12 ±0·42	61·4
Jackson	2·54 ,,	64·4

A further trial in the next year gave the following:

1932–3

Variety	Yield (tons per acre)	Per cent. of 'Table' tubers
Red Nut	5·17 ±0·53	88
Black Rock	3·23 ,,	80
Jackson	2·95 ,,	77

Occasion now arose to test a number of new seedling varieties which had been raised in Barbados by McIntosh [2]. Twelve of these were given a preliminary trial in 1934–5, as a result of which, six were carried on to the next year, when they were tested against Black Rock as a standard variety:

1935–6

Variety	Yield (tons per acre)	Per cent. of 'Table' tubers
B. 13	8·69 ±0·24	86·5
V. 52	7·56 ,,	94·1
Black Rock	7·30 ,,	86·5
B. 1	6·91 ,,	83·9
B. 5	6·79 ,,	87·1
B. 6	6·67 ,,	81·7
B. 2	6·35 ,,	90·5

In this trial, B. 13 was superior to all others at the 1 per cent. point; V. 52 was better than the last four at the 5 per cent. point.

Another trial carried out the same year in the south of the island, in rather different conditions, gave lower yields all round, but failed to

give any significant results, though B. 13, V. 52, and Black Rock were all at the head of the list.

The most desirable variety, however, is not necessarily the one which gives the heaviest yield. Three other points have to be considered before a decision can be made: the quality of the produce, its ability to stand storage, and the production of a large amount of green fodder. All these points have been borne in mind from the start. Notes of the quality were taken in the early experiments, and in 1935–6 a careful cooking test was carried out with the help of five disinterested judges, who awarded marks on the following scale:

Colour	Max.	50 per cent.
Flavour . . .	,,	40 ,,
Texture . . .	,,	10 ,,

Taste in Trinidad favours a root with a dark-coloured skin, with a white or cream-coloured flesh, a sweetish flavour, and a floury texture. V. 52 was awarded the highest marks, but its cream-coloured skin causes it to be regarded with some suspicion. B. 13, which was the heaviest yielder, was adjudged to be good in colour and texture, but so poor in flavour as to be almost unpalatable.

Storage is of first importance, for the price varies widely throughout the year, from about $1\frac{1}{2}$ cents ($\frac{3}{4}$*d.*) a pound in January to over 3 cents ($1\frac{1}{2}$*d.*) in August. Success in storing potatoes depends on the selection of sound undamaged tubers, and on humidity control, in order to strike a mean between a moist atmosphere which encourages decay due to micro-organisms, and a dry one which brings about a heavy loss in weight by drying. It is possible to ensure optimum conditions by constructing elaborate storage houses [3], but these are economically impossible for the peasant, and investigations have been limited to testing simple methods that are within his reach. Carefully selected, whole, unbruised potatoes were stored for various periods, in heaps, pits, or clamps, both ventilated and closed types being tested, and in sacks in a store-room. It was found that varieties showed great differences in their ability to store, as the tables on the next page show.

The most satisfactory method of storing has been found to consist in putting the roots in a clamp or in a shallow pit, lined with dry cane-trash or similar material, where they are arranged to a depth of not more than 12 in., and covered with more trash and a thin layer of soil. Over this, a light shelter of grass or palm-leaves is constructed to protect the heap from the rain and the sun. Such pits should be ventilated with bamboo tubes, which can be kept open or closed as thought desirable, and which also enable temperature-readings to be taken as required. Somewhat similar methods have been found successful in storing Irish potatoes in India [4].

Black Rock stands out from the others as a good storer, perhaps because it has a tough skin. Many of the roots were observed to sprout slightly, but this has apparently little effect on the edible quality of the roots. The heavy-yielding variety B. 13 is seen to be a very bad keeper, as well as being of poor quality.

Variety	Year	Method	Percentage loss from Drying	Percentage loss from Disease	Percentage recovery
Jackson	1930–1	Unventilated pit	18	29	53
	1931–2	Clamp	16	21	63
	1931–2	In sacks	10	5	85
	1931–2	Heaps in store-room	34	4	62
	1932–3	Clamp	19	55	26
	1932–3	In sacks	16	8	76
	1932–3	Shaded pit	31	44	25
Black Rock	1930–1	Unventilated pit	13	7	80
	1931–2	Clamp	10	1	89
	1931–2	In sacks	11	3	86
	1931–2	Heaps in store-room	14	1	85
	1932–3	Clamp	5	19	76
	1932–3	In sacks in store-room	16	4	80
	1932–3	Shaded pits	6	2	92
	1935–6	Shaded clamp	10	1	89
	1935–6	In sacks in store-room	9	1	90
Red Nut	1930–1	Unventilated pit	15	26	59
	1932–3	Clamp	18	62	20
	1932–3	In sacks in store-room	31	32	37
	1932–3	Shaded pits	25	42	33
V. 52	1935–6	In sacks in store-room	14	3	83
	1935–6	Shaded clamp	10	1	89
	1935–6	Shaded pit	19	14	67
	1935–6	Shaded clamp	18	7	75
B. 13	1935–6	In sacks in store-room	30	22	48
	1935–6	Shaded clamp	22	15	63
B. 1	1935–6	In sacks	10	8	82
	1935–6	Shaded clamp	20	12	68
B. 2	1935–6	In sacks	6	17	77
	1935–6	Shaded clamp	24	14	62
B. 5	1935–6	In sacks	10	18	72
	1935–6	Shaded clamp	19	13	68
B. 6	1935–6	In sacks	12	15	73
	1935–6	Shaded clamp	12·5	7	80

An experiment in spraying with 2 per cent. formalin showed that the practice conferred some immunity against the rot organisms (*Rhizopus*, &c.), but the tubers were badly scorched and their appearance was spoiled:

1935–6

Variety	Treatment	Percentage loss from Drying	Percentage loss from Disease	Percentage recovery
		%	%	%
V. 52	Sprayed *in situ*	10	3	87
	Sprayed: dried and stored in covered pit	16	4	80
	Unsprayed and stored in covered pit	19	14	67

A few figures have been recorded for the weight of vines obtained at harvest time:

Yield of Vines (tons per acre)

Variety	*1930–1*	*1931–2*	*1932–3*	*Mean*
Black Rock	1·08	6·5	7·36	4·96
Red Nut	1·37	5·8	6·35	4·50
Jackson	1·49	7·6	7·78	5·62

The crop in 1930–1 was poor, owing to unusually dry weather, and the other years are more typical. A variety possessing vegetative vigour will cover the ground more rapidly and thus obviate the need for excessive weeding, whilst a yield of some 4 to 5 tons of fodder is not to be despised. That it is of fair quality may be gathered from the following analysis [5]: dry matter, 33·9 per cent.; total digestible nutrients, 20·5 per cent.; nutritive ratio, 1 : 6·8.

These tests show that, on the average, in Trinidad, the best variety is Black Rock, a good all-round potato, which yields well, keeps well, and has an agreeable flavour. Two other useful varieties are Red Nut and Jackson, both of good quality and capable of heavy yields, but not good storing potatoes. V. 52 has many good points and may become popular in Trinidad. Black Rock and Red Nut were imported from Barbados by Dash about 1927; V. 52 is from St. Vincent; Jackson is a local potato.

Cultural Experiments

The sweet potato in the tropics is propagated from young vine-cuttings, some 18 to 24 in. long, and containing 3 to 5 nodes. These are generally planted on banks 3 to 4 ft. apart. In the West Indies these slips are inserted in the ground by means of a cutlass or a hoe. An experiment to compare these two methods of planting did not give a conclusive result, and it is probable that there is little difference between them in normal conditions. In dry weather, the deeper planting made possible by using the cutlass might result in a better 'take' of slips.

It has been found in the Philippines [6] that apical cuttings are superior to middle or base cuttings; they start earlier and ultimately give a bigger yield. The failure of Black Rock to establish, in 1932–3, was partly due to the great length of its vines; the kind of slips used varied much more than for Red Nut. Apical cuttings are also less likely to contain pupae of the vine borer, *Megastes grandalis*.

A system of planting on the flat, and ridging up the land subsequently, was compared with the more usual method of planting the slips on the top of ready-made ridges. The former method, if successful, might facilitate rapid planting when it was desirable to take advantage of favourable conditions, but it was also hoped that by earthing up the vines after they had been growing for some time, the attack of *Megastes*

would be reduced. The experiment showed, however, that ridge-planting was superior to flat-planting.

Year	*Yield in tons per acre from planting on*		Note
	Ridge	*Flat*	
1931–2	3·71	2·96	Diff. significant at 5% point
1932–3	3·72	2·39	,, ,, ,, 1% ,,

Weeding cost more in the ridged plots, but harvesting, even with the bigger crop, cost less, owing to the open nature of the soil. A series of soil-penetration measurements taken in 1932–3 at harvest time, six months after, still showed a slight difference between the treatments.

The spacing of the crop may be varied in two ways, between the banks and along the banks. In 1932–3 a comparison was made between planting 12 in. apart on 3-ft. banks and planting 9 in. apart on 4-ft. banks, but no significant difference was observed.

A comparison between planting at 8, 12, and 24 in. in a 3-ft. ridge also gave no significant differences. These results are rather surprising, but show that a wide latitude of distance of planting is permissible.

In the West Indies the normal practice is to dig out the tubers with a hand-fork, an expensive task. To improve upon it a special potato-lifting plough was obtained in 1931 from Messrs. S. L. Allen & Co., Philadelphia. This plough is fitted with two disc-coulters to cut the vines in front of the plough, a broad share, and bars in place of the mould-board. It was found that in the damp climate of Trinidad the vines are generally too green and tough for the cutting disks to work satisfactorily, though in drier conditions, in which the vines become dry and brittle, the discs should be more effective. In Trinidad the normal practice is to remove the vines before digging, and if this is done before ploughing, the plough works quite well, as will be seen from the table below, and, in a ridged crop, especially if the ridges are not more than 3 ft., effects a definite economy. It failed to work satisfactorily with a crop grown on the flat. The plough needs four oxen to draw it.

	1933 'Ridged' plot	*1935 Ridged*	*1935 Ridged*	*1933 'Flat' plot*
	lb.	lb.	lb.	lb.
Lifted by plough	961	237	261	890
Subsequently dug out . . .	70	8	6	505
Percentage of crop lifted by plough.	93	96·7	97·7	64
Percentage damaged or cut . .	1	..	..	1·5

Manurial Trials

Various combinations of organic and inorganic manures have been tried with this crop without obtaining any more definite indication than the value of organic manures for sweet potatoes. The value of

increasing doses of pen-manure is, for instance, clearly shown in the following:

1934–5

Treatment	(*Yield tons per acre*)
No pen-manure	4·50 ±0·25
5 tons pen-manure	5·62 ,,
10 tons pen-manure . . .	6·60 ,,

The results are significant at the 5 per cent. point.

The effect of pen-manure is more marked in a dry season, but at times fails completely, and it is difficult to explain an experiment in which dressings of 10 and 20 tons per acre of pen-manure, and of 830 lb. of a mixed mineral manure, failed to give any significant increase. All gave uniformly heavy and good crops.

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1926–7	Sweet potato variety trials	H. Musk and S. J. F. Dias.
1930–1	Sweet potato growing in Trinidad	W. T. Dalgarno.
1931–2	Sweet potato experiments	J. R. E. Hindson.
1931–2	A sweet potato variety trial	P. C. Chambers.
1932–3	Cultural and variety experiments with sweet potatoes	M. Halcrow.
1933–4	Some aspects of manuring in the tropics	R. J. M. Swynnerton.
1934–5	The place of certain organic manures in tropical agriculture	G. E. Tidbury.
1935–6	Variety tests on the sweet potato	B. de L. Inniss.
1935–6	Investigation into the manuring and storage requirements of sweet potato varieties	C. H. F. Walker.

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APPENDIX I

A brief account of the four main varieties is given below.

Black Rock. Leaves large, coarse, entire, cordate, dark green with a good deal of purple colour on the underside of veins and on the stem. Petioles long, vines long and straggly (6–10 ft.). Roots large, tapering. Skin bright purple; flesh white. Does not peel easily.

Red Nut. Leaves small, deeply lobed; dull green, tinged with purple at base; nodes very close, petioles short; vines short (3 ft.) and plant compact and bunchy. Tubers large, regular, and round; found near surface. Skin light red, flesh yellowish-white. Peels easily; a poor cover.

Jackson. Leaves medium to small, entire, cordate; trace of pink at base; petioles long, vines luxuriant, long and trailing (6–7 ft.). Roots large and spindly. Skin reddish-purple; flesh white. Peels easily.

V. 52. Leaves cordate; no pigment. Vines long and trailing. Roots large and tapering. Skin cream-coloured and tough; flesh cream-coloured. A quick starter and a good cover.

APPENDIX II

Labour Requirements for the Cultivation of an Acre of Sweet Potatoes in Men-days:

Crop 5 tons

	Men	*Women*	*Oxen*
Ploughing	2	..	4
Harrowing	½	..	1
Ridging	15–20	..	4
Planting	..	15–20	..
Weeding, first time	..	20–30	..
Weeding, second time	..	0–10	..
Lifting by hand and carting	24	4	1
	41½–46½	39–64	10
Lifting by hand	24	4	..
Lifting by plough	2	8	4

These figures may be considerably modified. The preliminary ploughing is often omitted entirely, and the land ridged up direct. The second weeding may not be necessary, and the labour needed for first weeding may be considerably reduced.

ROOT-DEVELOPMENT OF THE SUGAR-CANE IN BARBADOS

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WITH PLATE 8

Introduction.—The researches described in this paper were carried out during the growing-seasons of 1933–4 and 1935–6 with the objects of (*a*) obtaining information on the growth and development of the roots of several varieties of cane and the extent of their distribution at different ages; and (*b*) of determining relationships between growth and development of the above-ground parts and of the root-systems. Varietal differences in root-development were particularly studied. The possible practical value of the investigations would appear to lie mainly in the application of the results to sugar-cane breeding. Easy recognition of different types of root-system would aid materially in the selection of parent varieties, and in the allocation of resultant seedlings to distinct environments. This paper describes mainly the environmental conditions obtaining during the investigations and the experimental methods employed. The results obtained are treated in less detail, and for a full account the reader is referred to the original publications [1, 2].

Environment.—(*a*) *Soil.* The soil of the area where the investigations were made is typical of the shallow, black, coral-limestone soils of the low-rainfall districts of Barbados. The coral-limestone rock, from which the soil is derived, is situated from 2 to 3 ft. below the surface. The soil is a loam containing a high percentage of clay, but retains an excellent texture because it is fully saturated with lime. The pH value varies from 7·6 to 8·5. Under satisfactory rainfall conditions these soils are well suited to the growth of sugar-cane, and it may be confidently assumed that during the experimental periods available plant-food was at no time a factor limiting growth.

(*b*) *Rainfall.* The rainfall for the growing-season December 1932 to May 1934, the period of the first investigation, was 73·15 in., at Codrington Experiment Station, where the investigations were carried out. For the growing-season 1934–6, 69·09 in. were recorded. During the two seasons the rainfall distribution was approximately similar: rainfall was low from January to May, relatively high from June to December, and very low from January to May. The two seasons differed in that during the second investigation rainfall was comparatively heavy and well distributed early in the high-rainfall period, whilst the low-rainfall period towards the end of the second investigation was exceptionally dry.

Rainfall is by far the most important factor influencing the growth of sugar-cane in Barbados, and is the only acute limiting factor. McIntosh [3] has shown to what extent differences in rainfall and its distribution affect the growth and development of the above-ground parts of the sugar-cane, through their influence on such features as tillering, cane-growth, and drying-out of canes during the crop season. In this paper

certain aspects of the relationship between these factors and root-development are considered with special reference to the differential responses shown by varieties.

(c) *Temperature.* Mean monthly maximum and minimum temperatures at Codrington Experiment Station range from 69° to 87° F. Temperatures are lowest in January and February, then rise through March, April, and May. High temperatures are sustained throughout June, July, August, and September, thereafter the temperature falls progressively through October, November, and December. December means are little higher than those of January.

It is possible that the relatively low mean temperatures experienced during December and January, in conjunction with the shorter day-length of this season, are responsible, at least in part, for the diminished growth of old canes which occurs at this time of year. During these months mean minimum temperatures drop to about 60°–71° F. These temperatures are recorded during the night, when the sugar-cane makes most of its growth. Various investigators [1, 5] have shown the limiting effects of such temperatures on sugar-cane growth.

Experimental Materials and Methods of Study

Root-development has been studied in the following varieties: BH 10(12), Ba. 11569, B. 726, B. 2935, POJ. 2878, Co. 213, Co. 281, Uba, and *Saccharum spontaneum* (local Coimbatore form). The first four varieties are 'noble' canes (*Saccharum officinarum*), and are representative of the various growth-types met with in Barbados seedlings. POJ. 2878 is the Javan nobilization of glagah (*Saccharum spontaneum*), Co. 213 is a nobilized Chunnee (*Saccharum barberi*) seedling, and Co. 281 is derived from three *Saccharum* species (*Saccharum officinarum*, *Saccharum spontaneum*, and *Saccharum barberi*). Uba is the type-species of *Saccharum sinense*, and in our experiments we used the Indian form.

The field plots were established by transplanting single-eye cuttings from boxes, in order to obtain a collection of stools sufficiently uniform to be used in quantitative studies. The variety plot consisted of a row of three stools, planted 5 ft. apart, and at each examination one of these three-stool units was investigated for each variety.

During the growing-season records of tillering and cane-production were kept for each stool, so that these features might be compared with root-development.

In both investigations the stools were planted in the field plots in January, and root-development was studied at four times during the growing-season, viz. early in May, in August–September, in December–January, and finally in the following May. The last examination was made at the end of the dry crop season in order to relate such phenomena as rotting and drying-out of canes, which have an important bearing on root-development in Barbados.

Four distinct methods were used in the study of root-development at each examination, viz. (1) direct examination of root-systems in profile; (2) quantitative analysis of root-distribution by weight; (3) examination of stools removed from the field with adhering roots; and (4) a statistical

inquiry into the production of fibrous absorbing roots by the primary roots of varieties. Details of these experimental methods are given in the following sections:

1. *Direct examination of root-systems in profile.*—A trench, the depth of which was governed by the contour of the coral rock, was dug at a distance of about 9 in. from the stool-base line along one side of each three-stool variety plot. Care was taken to leave a vertical face on the trench wall on the side where the stools were situated. Immediately before the detailed examination of the root-systems, a further 3-in. layer was removed from the trench wall to leave a fresh surface beneath the stools. The final exposure of a vertical section of the root-systems was accomplished by spraying away the soil to a depth of about 3 in. into the trench wall by a jet of water. For this purpose a hand-operated barrel pump was used in conjunction with a long flexible hose and nozzle-attachment (Plate 8, Figs. 1 and 2). Accurate scale-diagrams of root-distribution were drawn as the work of revealing the roots proceeded.

This method is essentially that employed by Weaver and his associates in studying the root-distribution of various plant species in the United States [6], by Venkatraman in India [7], and by Jensen in Cuba [8]. It differs from that employed by these investigators in that the distribution of the roots was revealed by a cautious spraying in place of the picking method. The spraying method was found to be highly satisfactory, as the force of the spray was regulated so that the roots were not torn. Nutman [9] used an approximately similar method in his study of coffee.

2. *Quantitative analysis of root-distribution by weight.*—This phase of the investigations consisted in classifying and weighing the root-contents of soil samples. The same variety plots were used, but samples were taken from the sides remote from the trenches. Samples of 6 in. diameter and 6 in. deep were taken from three 6-in. soil horizons by means of a turf-cutter. Deeper sampling was rendered impossible by the presence of the loose 'rubble' horizon which overlies the coral rock.

Roots were recovered from the soil samples by treatment with running water in a sieve of 2-mm. mesh. The roots were washed clean, air-dried, and segregated into absorbing roots and non-absorbing roots before weighing. Absorbing roots were recognized by the presence of fine fibrous laterals, which have been shown to be the main bearers of root-hairs [1].

Several investigators [10, 11] have studied the distribution of the roots of sugar-cane by weighing roots that have been screened from the soil by sieves. In our investigations the method was used in conjunction with the other methods described here, and proved valuable in providing accurate quantitative figures upon which to base varietal comparisons of root-distribution and development. The writer is fully aware of the limitations of such a method when used *alone* to study differences between varieties in root-development and absorbing capacity.

3. *Stool examinations.*—At the conclusion of the examinations described in the two previous sections, all stools were cut back to approximately 1 ft. high, and removed carefully with a fork together with a foot or more of all the roots. A strong jet of water was used to free the stools from soil and to expose the roots. The individual cane bases and tillers

were then separated at their points of union, and the roots and their points of origin studied in the canes of varying age-classes. This examination was useful in helping to reveal the association between root and shoot development.

4. *Fibrous-root production from primary roots.*—Roots were finally cut from the cane bases, and those of each variety were bundled. Random samples of 30 roots were then taken from each variety-bundle and records made of the numbers of fibrous laterals occurring on the basal 1-ft. length of each root. From these records it was possible to establish varietal means, with their standard errors, and to estimate the significance of the differences between these means. This method was used during the second investigation only, having been devised to obtain more precise information on the absorbing capacities of the root-systems than was available in the first investigation.

Results of the Investigation

The more important findings of the investigations are presented for convenience under headings referring to the four times of examination mentioned above.

1. *First examination (May).*—Rainfall was low during the 1933–4 investigation, and the surface-soil was very dry. Roots arose from the tiller bases and penetrated vertically or obliquely into the lower soil-layers in such a way that the root-systems in profile resembled inverted fans below the stools. Penetration of the loose 'rubble' and regions of coral rock was sometimes seen. The roots showed characteristic gradations in form and colour. They were white, thick and turgid near the growing-point, and older regions were successively reddish-brown, with shrivelled cortex, and black with cortex dead and sometimes sloughed off.

Branching was rare in normal primary roots, but common where root-tips had been damaged or checked in growth. A few fine fibrous laterals occurred near the stool bases on the oldest regions of the roots. Such fibrous roots were from $\frac{1}{4}$ to $\frac{3}{4}$ in. long, and microscopic examination showed them to possess abundant root-hairs.

A successional aspect in root-production was observed, which was related to the development of new tillers in the stools.

Quantitative figures from the sampling analysis corroborated the findings of the direct examination. Root-content of the surface 6-in. soil-layer was low, and there was a greater mass of roots, with a wider distribution, in samples from successively lower layers. Varietal differences in root-distribution were small at this time, although total root-weights from the samples varied considerably, being appreciably larger in such early-tillering varieties as Co. 281 and POJ. 2878, and less in the 'noble' canes.

In the 1935–6 investigation soil-moisture conditions were more favourable, and a distinct response on the part of the root-systems was observed. Roots had grown in directions more nearly horizontal, with the result that the surface-soil layer generally contained a higher proportion of roots than in the previous investigation. In addition, branching and fibrous roots were more abundant, indicating that early favourable

moisture conditions had speeded up the developmental cycle in individual primary roots.

Varieties derived from wild species of *Saccharum* had significantly higher mean numbers of fibrous roots on the primaries than had the noble-cane varieties (*Saccharum officinarum*). Within the noble-cane varieties, moreover, differences were found in this respect which could be related to the vegetative-growth types of the varieties involved.

2. *Second examination (August–September)*.—The second examination followed a period of high and well-distributed rainfall in both seasons, with canes and tillers making rapid growth. Root-distribution in the soil had materially altered by this time, and new root-growth was taking place mainly in the surface-soil. Recently produced primaries followed directions close to the horizontal, frequently within a few inches of the soil surface. Branching and fibrous roots were plentiful.

The earliest roots, of the 'inverted fan' formation, were by this time old and black, but were generally still active, possessing white steles below the dead and shredded cortex.

Varietal differences were more marked than at the first examination, particularly in the 1935–6 season, when root-systems were more advanced in their developmental cycle on account of the early favourable rainfall referred to above.

The spatial distribution of roots in the soil again did not differ so considerably between varieties as did actual root-mass, which was seen to be clearly related to the development of above-ground parts.

It was in the quantitative study, where the proportion of absorbing roots in the systems was considered, and in the counts of fibrous roots, that more important varietal differences were revealed.

Absorbing roots were no higher, on a percentage basis, in the noble canes than in the early-tillering short-season nobilized types, whose roots appeared to pass rapidly through the stages of their developmental cycle and to become non-absorbing through early loss of fibrous roots.

The results of the two seasons' investigations showed that at this time the root-systems were further advanced in development in the 1935–6 season, being rather more superficially seated, and, generally, with a higher percentage of non-absorbing roots present. In mean numbers of fibrous roots on the primaries, 'noble' canes were now, with the exception of BH. 10(12), comparable with the nobilized varieties and wild species. It is important to note that BH. 10(12) represents an extreme in the range of 'noble'-cane growth-types included in the investigation, being characterized by slow early development and a long vegetative growth-period.

3. *Third examination (December–January)*.—Conditions since the second examination had been very favourable in both seasons, and all varieties had made excellent growth. 'Arrowing' (i.e. flowering) had occurred in all varieties except the 'noble' canes, in which vegetative development only had taken place. Cane-growth had almost ceased by this time in both seasons.

Varietal differences in the development of above-ground parts were rather marked at this time. Such varieties as Uba, Co. 213, Co. 281,

and *Saccharum spontaneum* had several tillers and young canes in addition to the old canes which made up the stools. Such tillers and young canes were generally few in the noble varieties, although in this respect differences in this group were noted, and related to the respective growth-types.

Root-development showed marked changes since the second examination. Definite signs of ageing were evident, with a fair proportion of the roots already moribund and of little value for absorbing. Superficial growth of primaries was still occurring, so that on a dry-weight basis the surface 6-in. soil-layer had generally more roots than the deeper layers.

In the quantitative sampling study it was found that, although total root-weights had increased appreciably since the second examination, there was a clear reduction in the percentages of the absorbing fraction in the root-systems. This would appear to indicate transition of absorbing to non-absorbing roots since the previous examination, due to the presence of large numbers of old black roots whose fibrous laterals had died, and which accordingly were classified before weighing as non-absorbing. The differences between varieties in percentage of absorbing roots present were appreciable, and could be related in most cases to the features of above-ground development which determine the growth-types of the varieties.

The 'noble'-cane varieties had now higher percentages of absorbing roots than the nobilized varieties and wild types, indicating a longer vegetative growth-cycle in their roots as compared with that in their canes.

The wild cane, *Saccharum spontaneum*, had produced a continuous series of tillers from underground rhizomes. This form represents the extreme short-season type, characterized by rapid early development and early flowering. In the roots the fibrous-root-bearing phase is evidently very short, so that by this time the percentage of non-absorbing roots was higher than in any other variety.

In mean numbers of fibrous roots on the primaries *Saccharum spontaneum* was significantly lower than all other varieties, a finding of interest in view of its very high figures at the earlier examinations.

Fibrous-root means were generally lower for all varieties except the extreme long-season type, BH. 10(12), which was by this time no longer inferior to the other varieties.

4. *Fourth examination* (*May*).—During the four months between the third and fourth examinations rainfall had been exceptionally low in both seasons, and moisture in the surface-soil was in both cases probably even less than at the first examination one year before. The examination was made shortly after the end of the reaping-season, when the stools were well past their maximum weight. Considerable drying-out of canes had taken place, more particularly in the 'noble' varieties.

Root-systems at this time were characterized by the presence of large numbers of thin, black, wiry roots in all soil horizons. Many of these were decaying, and were easily broken by the water-spray during the exposure of the profiles.

A marked deterioration had occurred since the previous examination

in the absorbing capacities of the root-systems, as judged by the presence of fibrous roots, which were evidently being lost rapidly by the moribund primaries. They were easily broken by the lightest water-spray, so that the water which settled temporarily in the trenches had a surface-scum of pale-brown fibrous roots. This condition had not been noted at any previous examination.

Late-produced canes and tillers had given rise to roots, which were characteristic in appearance in all varieties. These were brownish in colour, almost unbranched, and penetrated vertically or obliquely into the subsoil in a manner resembling the earliest produced roots at the first examination. Such roots frequently exhibited extreme distortion and flattening where growing in the hard dry subsoil.

Varietal differences in root-distribution at this time appeared to be related chiefly to the number of such late roots, which in turn was clearly related to the production of late shoots.

In the quantitative study all varieties showed, as was expected, large increases in the percentages of non-absorbing roots present. Non-absorbing roots were frequently recovered from the samples as short, broken pieces.

Differences in root-development between the stools of individual varieties were sometimes rather marked at this time. It was noted that, in general, where late canes and tillers were present in the stools, the root-systems were more sound and vigorous, and the older canes showed a lower percentage of rotting and drying-out than where old canes only were present.

There had been a general decrease in mean fibrous-root numbers on the primary roots since the previous examination. This decrease was, however, less appreciable in the case of BH. 10(12), whose mean number was now higher than those of all other varieties except B. 2935. Many of the roots of the short-season varieties such as Uba, Co. 213, POJ. 2878, and *Saccharum spontaneum* had completed their developmental cycle, and occurred in the random samples as dead, black roots completely devoid of fibrous laterals. There was clear evidence that such roots had once possessed abundant fibrous roots, which had subsequently died and dropped off, leaving characteristic minute pits and protrusions.

Summary and Discussion

The findings recorded above refer only to root-development under the environmental conditions obtaining during the investigations. The writer wishes to stress this point, for it is highly probable that in the root-development of varieties considerable differential responses to different environments would occur, more particularly as regards the soil. For this reason it would be hazardous to generalize from the results of our investigations in Barbados.

Many important features in the development of the root and the root-system, in the relationship between, and the effect of weather on, root and shoot, and the differences between varieties are illustrated by the findings described above.

All roots arising from the tillers and cane-bases are, in the writer's

opinion, fundamentally of one type, and it is only after their growth that differentiation ensues to provide recognizable types. That certain roots are eventually more effective as absorbing organs, and others as anchoring organs, seems purely incidental, and certainly depends on the conditions under which they are produced and grow in length.

Evans [12] has described three distinct sugar-cane root-types which he recognizes in Mauritius: superficial absorbing roots, buttress-roots, and rope-systems. That such a teleological classification is one of convenience only, and not based on any original fundamental difference between the roots themselves, is shown by him in a later publication [13]. He found, in an experiment in which the subsoil was thoroughly broken up before planting canes, that buttress-roots were not produced in the loosened subsoil even at a depth of 3 ft., but occurred only in the hard, undisturbed subsoil. In the treated zone, roots of the superficial type, which normally occur only in the few surface-inches of soil, occurred throughout. The effect of a loose friable soil—and probably of better aeration also—on the type of root produced was thus very clearly demonstrated.

The developmental cycle in the unit root-system, through stages of turgid cortex, shrivelled cortex, and dead cortex, with the production and subsequent loss of absorbing fibrous laterals, has been described above. Under Barbados conditions soil moisture would appear to have the greatest effect on the rate of this developmental change. It was noted that within one growing-season, or between comparable times of the two seasons experienced, early favourable soil-moisture conditions served to accelerate the developmental cycle in the roots. In addition, adequate soil moisture appears to favour surface-rooting, and low soil moisture, deep rooting. The effect of waterlogging could not be studied as it did not occur.

The *stool root-system* is comprised of the root-systems of the canes in the stool, and hence is represented by the summation of the unit root-systems present at any time. The growth and development of the stool root-system depend on the external factors already mentioned, and also on the degree, and, more particularly, on the time, of tiller production. The latter has been shown by McIntosh [3] to depend on the variety and the external conditions. Varietal differences in the development of the stool root-systems are ascribed partly to the different tillering periodicities in the varieties. This feature affects the drying-out of canes during a long dry reaping-season, for it appears that stools possessing late canes or tillers, by virtue of their having a young root-system, are enabled to absorb soil moisture and help maintain the soundness of their canes.

The effect of variety on the development and absorbing capacity of the root-system has been stressed throughout the investigations. It has been shown that while varieties differ little in the actual spatial distribution of their root-systems in Barbados, there are appreciable differences in the extent, and more particularly in the time, of production of fibrous absorbing roots. It would thus appear reasonable to conclude that varieties differ in their periods of maximum root-system efficiency, and that for any true comparison of variety root-systems the time factor is

Fig. 1. Method of revealing root-systems in profile by means of a regulated water-jet. Second examination (August).

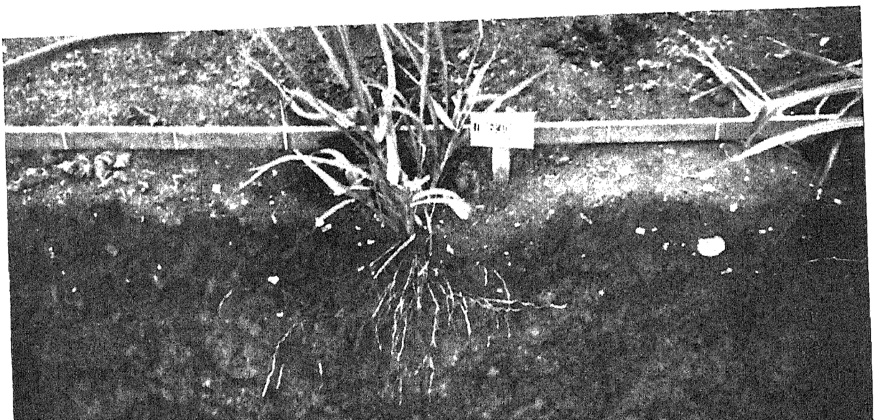

Fig. 2. Root-system of B. 726 in profile after exposure by spraying. First Examination (May).

an important one. Consequently, it appears to the writer that for a true understanding of varietal root-system development it would be wrong to compare the root-systems of varieties by making examinations at one and the same age only, even under identical environmental conditions.

The close relationship between root and shoot development has already been emphasized. It has been shown how, even within the noble-cane group, it is possible, by considering the time and extent of fibrous-root production, to recognize growth-types which correspond closely with those indicated by above-ground measurements of growth-increments and cane- and tiller-production over the growing-season. Although such a relationship is interesting, it is, for obvious reasons, far more convenient to segregate growth-types by measurement and periodicity of above-ground parts. For this reason it is felt that, as an aid to the breeding-work, root-system studies in Barbados, such as those described here, can have a limited value only.

It is admitted that up to the present the investigations have been carried out in soil which is very favourable to the growth of sugar-cane, and that important information might be forthcoming from studies in poor soils which will not produce satisfactory crops of 'noble' canes. Such soils do not occur in Barbados, but are found in certain of the islands of the British West Indies, and it is hoped that root-development studies under such conditions will be undertaken in the future.

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GREEN MANURING IN SOUTHERN NIGERIA

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A PREVIOUS paper in this journal by Faulkner [1] showed that although soil fertility could be effectively maintained at Moor Plantation by green manuring, it made little difference to the succeeding crop of maize whether the leguminous manure crop (*Mucuna utilis*) was buried green, or cut, allowed to dry, and burnt *in situ*.

This paper deals with the effects on the soil in 1936 of burning a green manure in contrast to burying it, on a Block (B 7 and 8) consisting of 17 plots of ¼-acre each. The field experiments had been carried on since 1931 at Moor Plantation, Ibadan (7·5° N. by 4° E.), where the annual rainfall is 50–55 in. There is a dry season from November to March, with a period varying from a week to a month (usually early in January) when a dry wind (the Harmattan) blows from the north and the humidity drops considerably. A definite break in the rains usually occurs during August, the bulk of the rain falling in June and September. The daily and nightly temperature-variation is approximately 90° to 75° F. throughout the year, except during the rains, when the daily temperature rarely exceeds 80°, and during the Harmattan period, when the night temperature may drop below 60°.

The soil is a light sand overlying an Ilẹpa profile [2]; mechanical analysis shows the following variations: Stones, 11·1–20·5 per cent. (mostly small concretions containing MnO_2 and some quartz); coarse sand, 51·7–59·1 per cent.; fine sand, 24·2–28·8 per cent.; silt and clay, 16·0–19·8 per cent. (about 75 per cent. of this is clay).

The lay-out of Block B 7 and 8 consists of 9 control plots, where the cover crop is dug in green, alternating with 8 'treatment' plots, where the cover crop is burnt *in situ*. The yields from the treatment plots are compared with the mean of those from the two adjacent controls. The method of working this out statistically is described by Faulkner in the 2nd Annual Bulletin of the Agricultural Department of Nigeria, July 1923. A difference between controls and treatments of twice the standard error is regarded as the minimum required for significance, giving odds of 43 to 1 that the observed results are not due to 'uncertain errors'.

The cropping of the block is as follows: early maize is planted at the beginning of April and *Mucuna* is sown through it in June; the maize is harvested in August; the *Mucuna* is cut in late November or early December on the treatment (even-numbered) plots and allowed to dry, when it is burnt *in situ*; on the control plots (odd numbers) the *Mucuna* is cut and dug in green more or less at the same time as the burning operations on the treatment plots. Both the green and the burnt material are incorporated immediately in deep ridges, and, as stated above, the early maize is sown at the beginning of April on the stale ridges.

Soil samples were taken at the beginning of May 1936 from every tenth ridge of each plot, there being 55 ridges in all, and subsequently

in early December 1936 in the same manner, just before the *Mucuna* was cut. The depth of sampling corresponded to the depth of the ridge. The five samples from each plot were thoroughly mixed together, and the resulting 17 composite samples were freed from stones and as far as possible from extraneous organic matter before analysis (the undecomposed organic matter consisted entirely of partly decomposed roots and stems, and leaves were never present).

The yields since 1932 have been as follows:

TABLE 1. *Average Yields of Maize on Green-manured and Untreated Plots*

Pounds per acre of Dried Grain

Year	*Average yield control (green) plots*	*Average difference treatment/control*	*Standard error*
1932	1,615	+90	±103
1933	697	+84	±31
1934	1,746	+56	±66
1935	1,689	+7	±85
1936	548	+132	±85

Thus only in 1933 was the increase in yield due to burning significant.

The yields in 1936 (the year of these investigations) were badly affected by an attack of the Army Worm (*Spodoptera Mauritia*), which destroyed most of the young seedlings, and the crop for the most part had to be resown. An unexpected drought during the later part of April severely checked the crop, and at the time of sampling the maize consisted of a thin patchy stand of stunted plants. The crop was also affected by the undue length of the intermediate dry season during July and August. The effect of the drought following the early rains and the poorness of the resown crop are reflected in the very high nitrate-content of the plots (*v.i.*).

Chemical Investigation

For brevity, the analytical figures are summarized under averages for control and treatment plots. The standard error was worked out from the figures for the individual plots, and all the data are given in Tables 2 and 3.

Nitrogen was determined by the Kjeldahl method, and was significantly greater on the control plots both in May and in December. There is an indication of a loss in nitrogen for both controls and treatments throughout the growing-season. Nitrates were determined immediately after sampling by the phenoldisulphonic-acid method of Harper, allowance being made for the moisture-content, which was determined at the same time. The high nitrate-content of the May samples has been explained above. The higher nitrate-content of the control plots was maintained throughout the season. There was naturally a big drop in nitric nitrogen for both sets of plots during the rains.

To check the nitrate figures, specific conductivities were determined

and the salt-content calculated by the method of Joseph and Martin [3]. The figures for calcium nitrate were calculated on the assumption that all the nitric nitrogen was present in that form in both 'green' and 'burnt' plots; and the figures for 'other salts' were derived from the figures for salt-content. The 'burnt' plots appeared to contain more soluble matter other than nitrates than the 'green' plots, and this would explain why,

TABLE 2. *Nitrogen and Salts*

All values (except specific conductivity and moisture) in parts per million of soil (significant differences marked)*

	Nitrogen	*Nitric N*	*Specific conductivity as* 10^{-6} *Mho*	*Salt-content*	*$Ca(NO_3)_2$ equivalent to N*	*Other salts*	*Moisture per cent.*
May samples:							
9 controls ('buried')	890	91	265	663	546	117	8·6
8 treated ('burnt') .	790	51	210	525	306	219	9·65
Treated/control .	−100*	−40*	−55*	−138*	−240	+102	+1·05*
Standard error .	±30	±9·9	±10·4	±26	..	..	±0·37
December samples:							
9 controls ('buried')	810	6	45·5	114	36	78	..
8 treated ('burnt') .	740	4	48·2	121	24	96	..
Treated/control .	−70*	−2*	+2·7	+7	−12	+18	..
Standard error .	±30	±0·8	±2·7	±7	..	..	..

TABLE 3. *Exchangeable Bases and Unsaturation*

	pH	*Exchangeable bases, total mg. equiv. per cent.*	*Bases absorbed at pH 7·2 mg. equiv. per cent.*	*Exchange-capacity mg. equiv. per cent.*	*Base-saturation per cent.*
May samples:					
9 controls ('buried') . .	5·9	5·75	2·68	8·43	68
8 treated ('burnt') . .	6·4	6·83	1·85	8·68	79
Treated/control . .	+0·5*	−1·08*	−0·83*	+0·25	+11*
Standard error . .	±0·06	±0·31	±0·13	..	±1
December samples:					
9 controls ('buried') . .	5·85	5·45	2·70	8·15	67
8 treated ('burnt') . .	6·4	6·46	1·84	8·30	78
Treated/control . .	+0·55*	+1·01*	−0·86*	+0·15	+11*
Standard error . .	±0·05	±0·42	±0·14	..	±2

although there was still a significant increase in nitrate-content of the control ('green') over the treatment ('burnt') plots in December, no such increase occurred in the total salt-content.

Moisture was determined as part of the routine in the nitrate determinations. The May figures only are included as no significant differences occurred in the December samples. The fact that the 'burnt' plots contained more moisture than the 'green' ones (which contain more organic matter) is hard to explain, unless the stems of the green crop made the soil too open. It is possible that the higher content of total electrolytes in the 'green' plots may have caused a greater flocculation of the clay and consequently raised the rate of drainage. It is also

possible that burning causes some clay-deflocculation through the production of sodium salts. As will be seen later, the pH value of the burnt plots is significantly higher than that of the controls; but neither of these explanations is put forward with any confidence.

pH values (Table 3) were determined by the colorimetric method of Kuhn. The quinhydrone method is unsuitable for these soils owing to the presence of manganese dioxide. The standard error has been worked out, regarding the pH units as an arithmetical series. As the range of differences in pH values is small, it is probable that the result can be regarded as significant. The results are in accordance with expectation. Total exchangeable bases were determined by the method of Rice Williams. Burning increased it, and the increase was maintained throughout the growing-season. Bases absorbed were determined by the paranitrophenol method of Schofield. The absorption was greater for the control than for the treatment plots. By adding the figures for total exchangeable bases and bases absorbed, the 'total exchangeable capacity up to pH 7·2' (pH 7·2 being the pH of the calcium paranitrophenol solution) was derived. Percentage base-saturation up to pH 7·2 was calculated from

$$\frac{\textit{total exchangeable bases} \times 100}{\textit{total exchangeable capacity}}$$

and the results fall into line with the pH values in the first column.

Available phosphorus (Table 4) was determined by the method of Lohse and Ruhnke, using a solution of potassium hydrogen sulphate as extracting medium.

TABLE 4. *Available Phosphorus (Parts per Million)*

	May	*December*	*Difference May/December*
Average for 9 control ('green') plots .	40	35	5 (loss)
,, ,, 8 treatment ('burnt') plots	63	45	18 (loss)
,, treatment/control . .	+23	+10	+13 (gain)
Standard error	±5·5	±5·2	±4·3
Significance	Yes	No	Yes

Whereas the 'burnt' plots contained a significantly greater amount of available-phosphorus in May, they lost much more of it during the growing-season than the 'green' plots, and the increase of the treatment over control is not significant in the December samples.

It must be admitted that subsequent work has shown that it is questionable how far the potassium hydrogen sulphate and other methods really make any distinction between what phosphorus is, and what is not, available to the plant in Nigerian soils. The fact, however, that there was a significantly greater drop in available phosphorus for the 'burnt' plots over the controls during the growing-season probably indicates that burning increases the available-phosphorus content.

Discussion

Briefly, the data obtained show that turning-in a cover crop when green increases the contents of nitrogen and nitrate in the soil, whilst burning the cover crop raises the pH value and the available-mineral content. These results are very much what would be expected. The surprising fact is that the differences in yields between the 'green' and the 'burnt' plots for the last five years are negligible, and the problem resolves itself into (*a*) whether the fertility of the 'burnt' plots will be maintained indefinitely, and (*b*) whether there is the same necessity for an additional nitrogen-supply under tropical conditions as there is in a temperate climate. Time will give the answer to (*a*), for these and other similar experimental plots are being continued indefinitely. As regards (*b*), Diamond and Hartley [4], and Wright [5], have shown that in Nigeria the production of nitrates is extremely rapid when the rains break after the dry season, and that a further 'flush' occurs after the short dry season in August. In this experiment the lack of crop and the drought following the first rains revealed this accumulation of nitrates, which would otherwise have been removed by plants or leached out by rain. A possible cause of the 'flush', other than the prevailing high temperature, might conceivably be partial soil sterilization during the dry season under the influence of a tropical sun. It is possible that this would affect the protozoa to a greater extent than the bacteria and allow the latter a free hand when the rains came. It was also observed that although the 'green' treatment produced the greater amount of nitrates, a very considerable quantity (bearing in mind that no green matter had been dug in for five years), which should be sufficient for the average crop, was present in all the 'burnt' plots. The nitrates on the 'burnt' plots can only be derived from: (i) the original supply of organic matter, (ii) the roots of the burnt *Mucuna* crop, and (iii) the nitrogen obtained from fixation processes, and it is interesting to speculate whether these sources will suffice to maintain the nitrogen-balance in years to come. Blackman [6] has pointed out that at temperatures higher than 47° F. (which is considerably lower than that in Nigeria) the rate of liberation of nitrates increases rapidly and nitrogen-supply no longer controls growth.

The increase in available phosphorus on the 'burnt' plots is interesting in view of Hartley's work [7] in northern Nigeria, where he found that available phosphate rather than nitrogen is the 'dominant' fertilizer on soils with a nitrogen-content of about half of those dealt with in this paper.

The results indicate that under the conditions of the experiment and for the period covered by them, applications of extraneous supplies of nitrogen were not needed by the crop; it would be interesting to ascertain by means of parallel experiments conducted under other conditions the extent to which they would be reproduced elsewhere. Oberholzer [8] considers that in arid regions the nitrogen-balance is maintained by active fixation, whereas humid soils are subjected to constant losses of nitrates through leaching and abundant plant-growth. It is also questionable how far strictly 'humid' conditions can be said to

prevail at Ibadan, where the annual rainfall is about 55 in., and previous work by the author [2, 9] has shown that the prevailing tendency on these soils is one of rise of soluble compounds, and that losses by leaching may occur only to a limited extent.

Summary

1. Analyses of soil samples taken at the beginning and end of the growing-season, at Ibadan, Southern Nigeria, from plots where a green crop had been dug in, are compared with those where it had been burnt.

2. For the last five years there have been no significant differences in yields between the succeeding maize crops.

3. Owing to the failure of the crop and a prolonged drought after the early rains, a large accumulation of nitrates occurred on both sets of plots, the 'green' plots containing more than the 'burnt' plots. At the end of the season the nitrate-content was considerably reduced, but was still slightly higher on the 'green' plots.

4. The content of soluble salt, other than nitrates, the pH values, exchangeable-base content, available-phosphorus content, and base-saturation were higher on the 'burnt' than on the 'green' plots.

5. The 'green' plots contained more total nitrogen, and absorbed more bases than the 'burnt' plots both at the beginning and end of the growing-season.

6. There was a significantly greater loss in available phosphorus from the 'burnt' plots than from the 'green' plots during the growing-season.

7. The necessity for nitrogenous manuring in the tropics is discussed.

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AN EXPLANATION OF THE EFFECT OF FARMYARD MANURE IN NORTHERN NIGERIA

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Introduction.—In a previous paper [1] results were presented which showed that very large increases in the yields of cereals at Zaria, Northern Nigeria, could be obtained by applying dressings of farmyard manure so small as one or two tons per acre. Experiments were also described which aimed at accounting for this very striking effect. It was found that the nitric-nitrogen content of manured plots was no higher than that of unmanured, and preliminary experiments with cyanamide rather confirmed the inference that nitrogen was not of prime importance.

Later experiments showed that nitrate of soda containing nitrogen in quantity equivalent to that in two tons of farmyard manure per acre gave about two-thirds the increase in yield. This fact, together with failure to obtain any response at all to equivalent dressings of finely ground rock phosphate, led to the erroneous conclusion that farmyard manure owed much of its effect to its nitrogen-content but had in addition a 'specific' effect which could not be simulated by chemical fertilizers.

The experiments now to be described show conclusively that as great, or greater, increases in yield can be obtained from equivalent quantities of nitrogen, potash, and phosphate in the form of readily available 'artificials'. They also show that phosphate is by far the most important of the three nutrients, but that it must be in a readily available form. It is not until quantities of superphosphate equivalent to two tons of farmyard manure are added that any return is obtained from nitrogenous manure.

Experimental Work

In view of the very low phosphorus-content of the soil—about 0·012 per cent. of P_2O_5 soluble in concentrated hydrochloric acid, and 2 p.p.m. of readily available phosphorus—the lack of response to rock phosphate in previous experiments was surprising. As this might be due to its low availability, an experiment was carried out in 1931 to determine the effect of much larger dressings, and to compare them with equivalent dressings of more readily available phosphate in the form of bone-ash. The dressings applied were 400 and 1,000 lb. rock phosphate (10·5 per cent. citric-soluble P_2O_5) and 320 and 800 lb. bone-ash (20·3 per cent. citric-soluble P_2O_5) per acre. These quantities contained the same total amounts of P_2O_5. No other manure was applied. The experiment was set out as a 5×5 Latin square on 1/20-acre plots. The first crop was guinea corn, and in the following season residual values were tested with bullrush millet followed by cotton. Yields were as given in Table 1.

The results with the first crop showed clearly that a large dressing of a poorly available phosphatic manure or a smaller dressing of a more available one could have a considerable effect on the yield of guinea corn.

This was satisfactorily confirmed by the yield of millet in the following season; and the seed-cotton yields also showed a similar tendency. No apparent gain accrued from increasing the dressing of bone-ash above 320 lb. per acre.

TABLE I

Treatment	*Guinea corn* *1931* *lb. per acre*	*Millet* *1932* *lb. per acre*	*Seed-cotton* *1932* *lb. per acre*
1. Rock phosphate, 400 lb. per acre	1,396	496	376
2. ,, ,, 1,000 lb. per acre	1,560	604	422
3. Bone-ash, 320 lb. per acre	1,600	692	485
4. ,, 800 lb. per acre	1,680	640	428
5. No manure	1,204	424	378
Difference needed for significance	94	135	72

There was now clear evidence that the crop would respond if sufficient available phosphorus was present. In 1933 an experiment was set out to compare the effect of one and two tons of farmyard manure with mixtures of artificials containing the same amounts of nutrients in readily available form—nitrate of soda, superphosphate, and muriate of potash. The six treatments were as shown in Table 2.

TABLE 2

No.	*Letter*	*Treatment*
1	O	No manure.
2	F	One ton per acre farmyard manure.
3	NPK	A mixture of nitrate of soda, superphosphate, and muriate of potash containing nitrogen, P_2O_5, and K_2O equal to those present in one ton per acre of farmyard manure.
4	2F	Two tons per acre farmyard manure.
5	FNPK	Treatments 2 and 3 together.
6	2(NPK)	The equivalents in artificials (as No. 3) of two tons of farmyard manure.

These treatments were randomized on 6 blocks of 1/16-acre plots. The crop grown was cotton. The farmyard manure contained (per cent.): nitrogen 1·09, P_2O_5 0·35, and K_2O 1·58; so that the dressings of artificials equivalent to 1 ton per acre of farmyard manure were (lb. per acre): nitrate of soda 160, superphosphate 64, and muriate of potash 72.

The results were emphatically in favour of the artificial manures: NPK was as good as 2F, FNPK was not significantly better than 2F, but 2(NPK) was better than 2F. The same dressings of manure were applied to the same plots in 1934 with the exception that inorganic nitrogen was omitted from Treatment 5. Guinea corn was grown on this occasion with results identical with those obtained in the previous season. The omission of nitrogen from the farmyard manure and artificials made no change in the value of this treatment. A final crop of sweet potatoes, grown without further manuring, showed significant residual effects from 2F, FPK, and 2(NPK) (Table 3).

TABLE 3

Treatment	Seed-cotton 1933 lb. per acre	Guinea corn 1934 lb. per acre	Sweet potatoes 1935 lb. per acre
1. O	169	530	3,272
2. F	248	727	4,072
3. NPK	341	1,037	4,051
4. 2F	348	1,037	5,309
5. FNPK	363	..	..
FPK	..	1,171	4,836
6. 2(NPK)	427	1,457	4,749
Difference needed for significance	78	231	1,296

A second field experiment started in 1933 aimed at deciding whether the bedding portion of the farmyard manure had any significance. In 1931 applications of bedding-grass with and without inorganic nitrogen had been tried without success [1], but as the grass had then to be used in its dry fresh condition, it was desirable to repeat the experiment with rotted material. Four treatments were tried in 1933 with material obtained by rotting down bedding-grass with water in a pit (Table 4).

TABLE 4

No.	Letter	Treatment
1	O	No manure.
2	2 F	Two tons per acre farmyard manure.
3	2 R	Rotted grass containing organic matter equal to that in 2 tons of farmyard manure.
4	2(RNPK)	Treatment 3 *plus* inorganic N, P, and K to make the mixture equivalent in nutrients to 2 tons of farmyard manure.

These four treatments were set out in a Latin square of 1/16-acre plots, on an area immediately adjacent to the first experiment, and the same farmyard manure was used in each case.

The yields of seed-cotton in 1933 and of green gram grain (without further manuring) in 1934 are given in Table 5.

TABLE 5

Treatment	Seed-cotton 1933 lb. per acre	Green gram grain 1934 lb. per acre
O	135	141
2F	306	336
2R	111	162
2(RNPK)	454	489
Difference needed for significance	87	93

Obviously, rotted grass alone has no manurial value, and as the yield from treatment 2(NPK) in the one case is practically identical with that given by 2(RNPK) in the other, there seems to be no reason to think that it is useful as a supplement to a mineral mixture.

By the end of 1934 it was clear that it could no longer be contended that farmyard manure has a value exceeding that of the main plant-nutrients that it contains. There was also some indication that phosphate was of major importance.

In 1935, therefore, an experiment was arranged to test all possible combinations of inorganic nitrogen, phosphate, and potash, against farmyard manure, and against each other, both with and without farmyard manure. The standard dressing was 1 ton per acre of normal farmyard manure (F), and the dressings of nitrate of soda (N), superphosphate (P), and muriate of potash (K), contained quantities of nitrogen, P_2O_5, and potash equal to those present in 1 ton of farmyard manure. Sixteen treatments were necessary and were replicated in eight randomized blocks of very small plots. Each plot was $12 \times 12\frac{1}{2}$ ft. and carried 20 guinea-corn plants. In dealing with such small plots it was necessary to do more intensive cultivation than would be practicable on a large scale, and consequently the high yields shown in Table 6 would not normally be obtained.

TABLE 6

Treatment	*Guinea corn, 1935* Grain lb. per acre	*Guinea corn, 1935* Stems and leaves lb. per acre	*Guinea corn, 1936* Grain lb. per acre
O	670	5,010	270
N	635	5,010	227
K	798	5,660	358
NK	590	4,790	175
F	1,234	9,950	387
FN	1,188	9,720	435
FK	1,170	10,100	445
FNK	1,161	10,000	390
PK	1,198	9,840	449
P	1,340	10,450	523
NP	1,360	12,260	465
NPK	1,396	11,940	498
FP	1,778	14,660	547
FPK	1,730	14,400	675
FNP	1,840	17,200	695
FNPK	1,895	17,100	598
Difference needed for significance	189	1,560	..

It so happened that the sample of manure available for this experiment was almost exactly half as good as normal, so that two tons per acre were actually used, and they were regarded as equivalent to one ton of the manure used in previous and subsequent experiments. The actual com-

position was (per cent.): nitrogen 0·549, P_2O_5 0·174, K_2O 0·512. The corresponding dressings of artificials were (lb. per acre): nitrate of soda 162, superphosphate 60, and muriate of potash 47.

The grain-yields fall into four groups:

(*a*) No manure, and artificials other than phosphate.
(*b*) Farmyard manure, and farmyard manure+artificials other than phosphate.
(*c*) Artificial manures containing phosphate.
(*d*) Farmyard manure+artificials containing phosphate.

All the yields in group (*a*) are significantly worse than those in groups (*b*) and (*c*), and all the latter are significantly worse than those in group (*d*), but none of those in (*c*) are significantly better than those in (*b*), although the general suggestion is one of superiority.

It follows that mineral nitrogen and potash are of no value when used either alone or together, and whether farmyard manure is present or not. Potash, although giving some increase by itself, seems to depress yields when combined with nitrogen or phosphate (cf. K with NK, and P with PK). Phosphate, which gives as good a yield as farmyard manure, is therefore presumably the most important constituent of the latter, at least on Samaru soil.

The addition of farmyard manure to phosphate increases the yield, whereas the addition of inorganic nitrogen does not. As farmyard manure contains both nitrogen and phosphate it is presumably acting as a source of the latter rather than the former, but there is also a suggestion that extra nitrogen is of value in the production of grain when the phosphate reaches a certain limit (cf. FP and FNP). This certainly applies to vegetative growth, which is always greater in the treatments where nitrogen and phosphate are used together than in those where phosphate is used alone.

In 1936 this experiment was replanted with guinea corn to determine the residual values of the various treatments. Owing to the smallness of the plots, the usual thorough cultivation before sowing was impossible. Consequently the stand was very poor, and the crop failed entirely on one block and on several odd plots. The figures are shown in the table, and although no statistical significance is claimed for them they fit the grouping of the previous year's yields and show distinct residual effects from superphosphate and farmyard manure, the effect being greatest where the two had been applied together.

In 1936 a further experiment was laid out to test the main findings of the above small-plot experiment on a more practical scale. It was decided that potash treatments could be omitted, but that nitrogen had better be included owing to its possible value in the presence of larger quantities of phosphate. The following seven treatments were carried out in twelve randomized blocks of 1/20-acre plots (Table 7).

The farmyard manure contained 1·01 per cent. of nitrogen and 0·30 per cent. of P_2O_5, so that the corresponding dressings of nitrate of soda and of superphosphate were 150 and 52 lb. per acre, respectively. The yields obtained are shown in Table 8.

TABLE 7

No.	Letter	Treatment
1	O	No manure.
2	N	Nitrate of soda, N equal to that in 1 ton of f.y.m. per acre.
3	P	Superphosphate, P_2O_5 equal to that in 1 ton of f.y.m. per acre.
4	NP	Treatments 2 and 3 combined.
5	2P	Superphosphate, P_2O_5 equal to that in 2 tons of f.y.m. per acre.
6	N 2P	Treatments 2 and 5 combined.
7	2F	Two tons of f.y.m. per acre.

TABLE 8

Treatment	Guinea corn, 1936	
	Grain lb. per acre	Leaves and stems* lb. per acre
O	498	3,370
N	641	6,570
P	938	7,830
2F	978	9,000
NP	985	11,000
2P	1,042	10,280
N 2P	1,120	11,600
Difference needed for significance	140	1,720

* The produce from seven blocks only was weighed.

With the exception that nitrate of soda alone has given a just significant increase in grain-yield the figures might have been forecast from the previous year's results. The grain-yields of treatments P, 2F, and NP are almost identical. Doubling the dressing of superphosphate does not give a significant increase in yield, but doubling this dressing and adding nitrate of soda does.

These results confirm two suggestions already made with respect to the 1935 experiment, viz. that farmyard manure is as important as a source of phosphate as a source of nitrogen, and that the addition of mineral nitrogen is only of value when the phosphate has exceeded a certain limit. This limit apparently corresponds to the phosphate in 2 tons per acre of farmyard manure.

Chemical Work

Determinations of available phosphate were made on the plots of the 1931 experiment (rock phosphate and bone-ash) by the citric-acid method at the time, and by Lohse and Ruhnke's [2] potassium-bisulphate method subsequently. Neither set of figures showed any relation to treatments. As 1,000 lb. of rock phosphate should have corresponded to about 43 parts per million of available phosphorus, this result is somewhat surprising. The values found ranged between 6 and 46 parts per million.

In the 1933 experiment, determinations of available phosphate were again made, but as the single dressing of superphosphate corresponded only to about 1 p.p.m. of phosphate it was hardly expected that figures of any value would be obtained.

Nitric nitrogen was also determined in samples from the plots of the 1933 experiment. The dressing of inorganic nitrogen is reasonably large and its presence is consequently easily detected. The following table shows the results of determinations made from June to August according to Harper's method [3].

TABLE 9

	Nitric nitrogen in parts per million of soil												
Treatments	*June 2*	*June 9*	*June 16*	*June 23*	*July 3*	*July 10*	*July 17*	*July 24*	*July 31*	*Aug. 8*	*Aug. 14*	*Aug. 28*	*Sept. 4*
A. No manure	12·0	8·3	9·9	5·6	5·7	6·6	8·6	4·6	3·4	2·5	3·8	2·4	2·1
2F.y.m.	9·9	8·3	11·1	8·4	8·1	7·7	10·4	8·1	5·8	3·4	3·6	1·5	1·7
Rotted grass	12·2	10·0	8·9	6·7	7·0	8·3	10·4	7·0	7·0	3·3	4·6	2·1	2·1
Rotted grass +NPK	9·9	7·7	11·1	61·6	18·5	18·6	20·0	9·7	6·4	1·8	2·4	1·2	1·2
	June 6	*June 13*	*June 20*	*June 24*	*July 3*	*July 10*	*July 17*	*July 24*	*July 31*	*Aug. 8*	*Aug. 14*	*Aug. 28*	*Sept. 4*
B. No manure	12·2	10·0	5·2	7·2	6·2	7·6	9·4	7·3	6·8	3·6	4·8	1·7	2·2
F.y.m.	9·9	8·7	10·2	5·6	4·4	5·5	10·3	4·6	5·2	2·5	3·0	1·9	2·1
2F.y.m.	12·1	13·2	12·8	13·0	18·4	16·5	13·7	14·9	6·9	5·8	2·9	1·5	2·1
NPK	13·3	11·0	12·7	99·6	22·7	16·2	27·8	19·5	19·0	7·2	4·8	2·4	1·4
2NPK	9·8	7·7	6·3	95·2	27·5	36·8	62·5	39·8	19·4	13·3	8·1	1·3	1·4
F.y.m.+NPK	13·3	12·2	7·5	3·9	13·8	16·3	23·0	12·1	12·6	17·8	2·9	1·5	2·1

One ton of farmyard manure has no effect on the nitrate-content. In this experiment two tons have increased it, despite previous results to the contrary [1]. The effect of nitrate of soda is very notable, and persists until the middle of August—the wettest month—on the double-dressed plots. The presence of added organic matter, whether farmyard manure or grass, depresses the amount of nitric nitrogen set free by the nitrate of soda.

The specific conductivities of 1 : 5 water-extracts were also measured. They follow the nitrate-contents very closely, and are disappointing in that they show an equal level of salt-content in all the plots by the end of August. The specific conductivities on June 23 on the plots receiving organic matter as well as nitrate of soda have not been affected by the same depression as the nitric-nitrogen contents.

The pH of different plots, as determined by Kuhn's colorimetric method, varied from 5·6 to 6·3, and between the beginning of June and the end of August all plots, irrespective of treatment, showed a fall of about 0·3, the range on August 28 being 5·4 to 5·8.

A few nitrate determinations were carried out in 1934 and 1935, but no points of interest arose.

TABLE 10. *Specific Conductivity of 1:5 Water-Extracts*

	June 9	*June 23*	*July 3*	*July 31*	*Aug. 28*
A. No manure	33	28	34	20	21
2F.y.m.	35	35	35	27	23
Rotted grass	34	30	36	21	19
Rotted grass+NPK	28	240	101	32	23
	June 13	*June 23*	*July 3*	*July 31*	*Aug. 28*
B. No manure	37	39	40	29	20
F.y.m.	41	33	30	35	21
2F.y.m.	67	84	81	40	25
NPK	42	132	95	69	31
2NPK	40	249	132	92	30
F.y.m.+NPK	33	246	66	66	27

Discussion

It is clear that under the conditions obtaining at Zaria phosphatic manures are more necessary for arable crops than either nitrogenous or potassic. This result is well in keeping with analytical data concerning the soil, which contains 0·012 per cent. P_2O_5 soluble in concentrated hydrochloric acid, and about 2 p.p.m. of readily available phosphorus. It is generally known that this is also true of phosphate-deficient soils in other parts of Africa. At Samaru no response at all has been found to potash fertilizers, and nitrogen seems only to be useful when applied in conjunction with larger dressings of phosphate. The total nitrogen-content of the soil is only about 0·04 per cent., so that one would expect a response to nitrogenous fertilizers. Observations almost identical with those here recorded have been published in South Africa by Hall [4]. Working with various mixtures of N, P, and K on potatoes, he found no response whatever to potash, and a response to nitrogen small in comparison with that due to phosphate. In his experiments the nitrogen and potash manures were tested only in conjunction with the largest dressing of superphosphate (1,000 lb. per acre). Craig [5], working with phosphate-deficient soils and sub-soils in Mauritius, has shown by means of pot experiments that although a sub-soil supplied with nitrogen is practically unable to support plant-growth, yet when phosphate or farmyard manure is also added it is as fertile as the top soil with added nitrogen.

Throughout the experiments described in this paper and the previous one [1], the response to rock phosphate alone has been very poor unless it has been applied in large dressings, and the residual effect has not been great. On the other hand, the response to dressings of 50 or 100 lb. superphosphate has been considerable, and the residual effect, at any rate into the second season, has been almost as great. These results are quite different from those obtained in South Africa, where Alder [6] has shown that although superphosphate or basic slag may give a better return than rock phosphate in the first season, the total return over a period of years will be greater from the rock phosphate. Husband [7], in Rhodesia, has found the same relation to hold good between 'bones and superphosphate' and rock phosphate.

There are conflicting views about the mechanism of nitrification in tropical soils, but there is no doubt that the process is extremely rapid at the high temperatures involved, and particularly at the beginning of the rainy season. Working under temperate conditions, Blackman [8] has suggested that above 47° F. the rate of nitrification is so high that additional nitrogen is of no value to grassland.

When it has been possible to carry on an experiment for a period of years without the addition of organic manures, it may be that the natural reserves of nitrogen—and also potash—in the soil will become so depleted that the addition of appropriate fertilizers may be of value. Hall [9] suggests that this time has now arrived in South Africa on old farmland which in the past has received only phosphatic manuring.

Mention may be made of observations on another of the Department's farms near Zaria on similar, though originally rather better, soil. Blocks were cleared from bush and brought into cultivation at irregular intervals between 1924 and 1932. The block cleared in 1932 contained 0·078 per cent. nitrogen, whereas one cleared 8 years earlier contained 0·039 per cent. Owing to adverse circumstances this block had received practically no manuring since it was cleared, and would no longer carry a crop of guinea corn. In 1933 and early 1934, various poor green-manure crops were grown and turned in. A late-season hay crop of maize and cowpeas in 1934 yielded only 1,000 lb. per acre, but a dressing of 1 ton per acre of farmyard manure in 1935 produced a normal crop of 900 lb. per acre of guinea-corn grain. By that time the nitrogen-content had fallen to 0·029 per cent., and it is interesting to speculate whether the farmyard manure was still acting primarily as a source of phosphate, or whether the time had come when added organic matter was necessary as a source of nitrogen. Further work on such 'farmed-out' land is obviously required.

Summary

Field experiments have been described which show that the remarkable returns obtained from small dressings of farmyard manure at Samaru, Zaria, are to be attributed very largely to the phosphorus which it supplies. Similar increases in yield can be obtained from equivalent dressings of superphosphate, but not of rock phosphate.

The value of artificial nitrogenous manures is doubtful, and potash manures are almost certainly unnecessary.

Acknowledgements

The author expresses his thanks to the Director of Agriculture, Captain J. R. Mackie, and to the late Director, Mr. O. T. Faulkner, for their helpful criticism during the course of the work. Also to the Senior Chemist, Mr. H. C. Doyne, for much help in the preparation of the paper for publication, to him and Mr. W. A. Watson for carrying on the work while the author was on leave; and to the various Agricultural Officers who have been in charge of Samaru Farm, and without whose whole-hearted co-operation the work could not have been completed.

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FLUCTUATIONS IN THE NITROGEN-CONTENT OF SOME NIGERIAN SOILS

Pt. I. FLUCTUATIONS OF NITRIC NITROGEN

W. E. de B. DIAMOND

The three main factors affecting nitrification in soils are moisture, aeration, and temperature. The last was not a limiting factor in the soils investigated at Ibadan, Nigeria, in 1926–30.

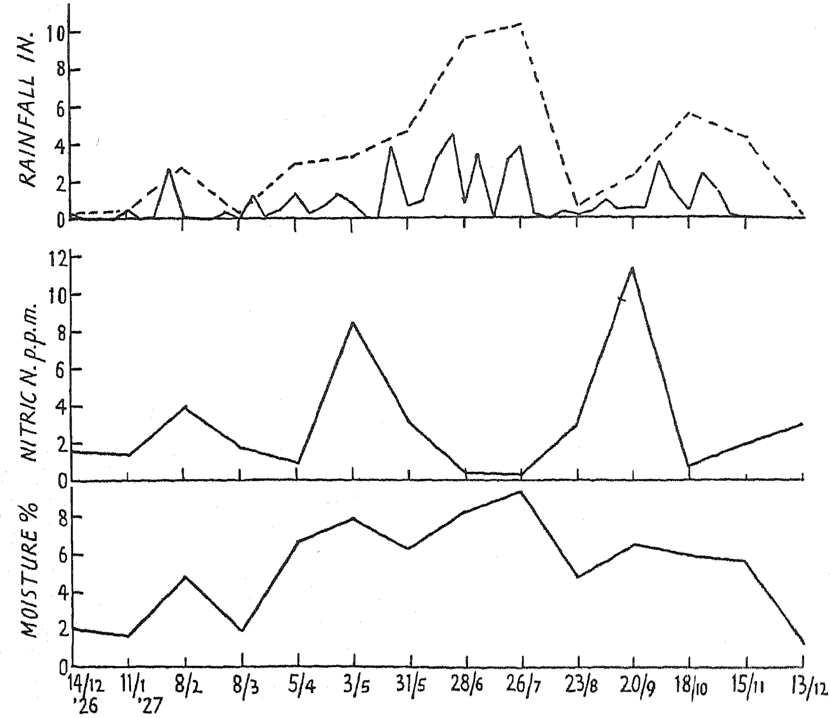

Fig. 1. Block A3. Average monthly nitrate- and moisture-contents for 1926–7, together with the monthly rainfall (broken line - - -), weekly rainfall (solid line ——). In all these figures the nitrate is plotted as nitric nitrogen in parts per million.

In Fig. 1 are recorded the average monthly contents of nitrate and moisture together with the monthly rainfall at Ibadan (lat. 7° N., long. 4° E.) for eight similarly cropped plots (block A3) for the period Dec. 1926 to Dec. 1927. Since the maximum standard error of the eight plots on any one date, except on April 5 and May 3 and 21, was not more than ± 1 part per million they provide a substantially accurate record of the data. The results for plot 21, which were much higher on these dates, were not included in the mean.

Similar records were obtained on five plots (block YB) during the same year and for six plots (block Y1) from Oct. 1927 to Jan. 1931. As the records for these plots were complicated by differences in the treatment of cropping and cultivation, they are not referred to in detail, though a record of three of the series, viz. Y1 Plots 14, 15, and 19, is shown in Fig. 2.

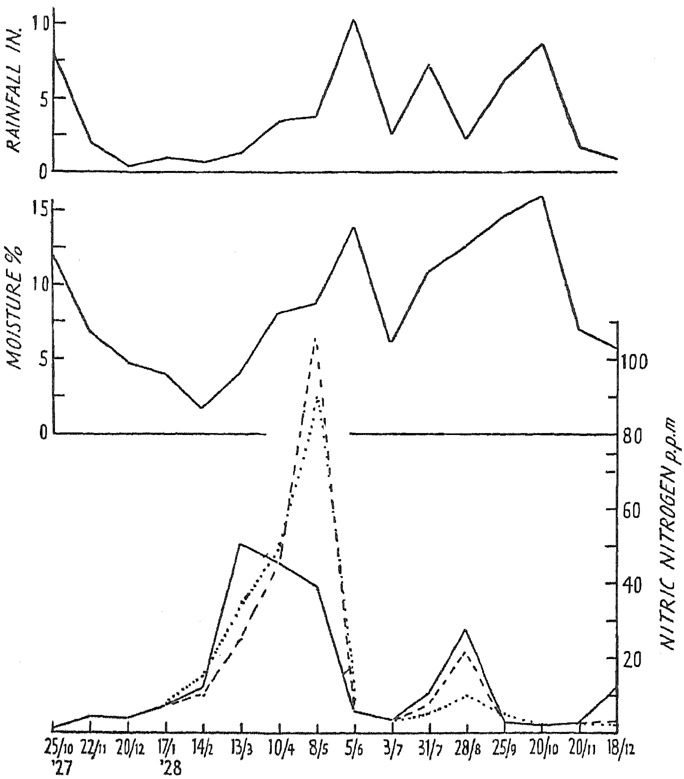

FIG. 2. Monthly nitrate-content and mean moisture-content for three plots on block Y1 for 1927–8, together with the monthly rainfall. Plot 14, solid line; plot 15, broken line; plot 19, dotted line. Plots 15 and 19 were control plots and received the same cropping treatment.

Fig. 1 also shows the general trend of the fluctuations of the nitric-content of the soils throughout the year. The qualifying term 'general trend', must, however, be interpreted in a wide sense for, as will be seen later, the actual content of nitric nitrogen in parts per million during May and September was considerably lower than that recorded for other plots and, what is more important, the maximum value recorded in the spring is normally considerably higher than that recorded in the autumn.

These results were confirmed in a series of determinations on other plots, especially on block Y1, continued from June 1928 to June 1930. The values from plot to plot on block A3, shown in Fig. 1, are particularly uniform, as the plots were all uniformly cropped, and were somewhat low

in fertility. The values recorded for the other plots, e.g. those in Fig. 2, are not so uniform: nevertheless they confirm the seasonal variations in the nitric-nitrogen content of the soils. Many of the variations in the values from plot to plot in any one series of determinations can usually be explained, either wholly or in part, by reference to the record of cropping or cultivation, or to climatic factors, more particularly the rainfall. One or two examples will be given to show to what extent such explanations may help to interpret the data obtained.

The most important factor affecting nitrification is rainfall. In Fig. 1 the mean monthly rainfall has been plotted above the graph for the nitric-nitrogen values, and it will be seen how closely the two are correlated. In February there was an exceptionally heavy rainfall of 2 in., the immediate effect of which is seen in the values obtained in the subsequent sampling on Feb. 8, 1927. This sudden spurt was checked by the seasonal dry weather which followed. The normal spring seasonal nitrification begins with the onset of the rains from about the middle to the end of March. The nitrification appears to increase to a maximum about the end of May to the beginning or first fortnight in June, and then to drop rapidly to a minimum as the monthly rainfall increases. Following a period of intense nitrification, it seems usual for a period of rest or reaction to follow. If this is true, then there would have been practically no nitrification going on, in spite of the otherwise favourable conditions, to make up for the losses.

After remaining at a minimum throughout the short dry period in July and the beginning of August, a further stage of active accumulation of nitric nitrogen sets in, generally about the end of August: it reaches a maximum about mid-October, and then declines to a minimum. The low nitric-nitrogen content continues throughout the dry period, until the cycle is renewed with the onset of the spring rains the following year. This illustrates the general trend of the seasonal fluctuations of the nitric-nitrogen content.

The effect of cultivation on the moisture- and nitrate-contents for plots on block A3 in 1927 is shown in Table 1. The differences in moisture

TABLE 1. *Effect of Cultivation on Nitrate-content, Block A3, expressed as Parts per Million of Nitric Nitrogen*

Plot	*Date of ridging*	*Moisture* %	*Nitric Nitrogen* (*p.p.m.*)	*Amount of rain after ridging* (*in.*)	*No. of days between sampling and ridging*
21	March 29–30	6·12	8·0	1·28	6
19	April 1	7·30	2·0	0·30	4
17	April 4	9·12	0·45	0·30	1
16	April 1–4	9·39	1·2	0·30	1
8	April 4–5	6·51	0·80	..	Being ridged when sampled
6	April 5	5·30	0·80	..	Being ridged when sampled
4	April 8–9	5·32	0·40	..	Unridged
3	April 9	5·45	0·25	..	Unridged

content were caused by the increased percolation on the cultivated plots; on the uncultivated plots there was also a certain amount of run-off.

The values obtained for nitrate-content followed closely the date of cultivation; thus plot 21, which had been re-ridged six days before the sample was taken, has the highest content, 8 p.p.m., whilst the uncultivated plots had only a trace of nitrate. Arising out of this and other observations made during 1927, further work was begun on the effect of cultivation. The results were published in 1931 [1].

In striking contrast to the values obtained on the cultivated plots the uncultivated or 'bush' soil seldom contained more than a trace of nitrate; at most between 2 and 3 p.p.m. This soil, a coarse-sand soil, came from a native farm that had been allowed to go out of cultivation; the surface had become consolidated, so that aeration was bad and conditions were unfavourable to nitrification. Hall [2, 3] has recorded similar conditions obtaining in uncultivated virgin land in South Africa.

Weekly determinations of nitric nitrogen.—Weekly determinations of moisture and nitrate on plot YB 16 were started in Aug. 1927, and in Oct. 1927 a cultivation experiment was begun. In 1928 it was recorded that 'these results show that there was considerable fluctuation of nitrate-content from week to week, and again illustrate the close connexion between moisture and nitrate-accumulation'.

In Dec. 1927 the monthly determinations, which had been started on six plots of block Y1, were continued at weekly intervals up to Aug. 1928 on three plots (Nos. 14, 17, 18) in order to obtain further information on the decomposition of green manure. From Aug. 1928 to Jan. 1929 the determinations were made at fortnightly intervals; and then continued at weekly intervals until the beginning of April. The work was then unavoidably interrupted, though the monthly determinations were carried on, until it was resumed again in Dec. 1929, and then continued to May 1930. There is thus a series of records available for the same plots for three years.

Many observations and correlations between cropping and cultivation have been obtained from these records. It will suffice here to refer to a typical record, shown in Fig. 3, for plot Y1 14.

The curves show the close correlation between moisture-content, and hence rainfall, and nitrification. As in the monthly records, the fluctuations in each plot tended to follow a similar course from year to year, as shown by the parallelism of the graphs.

A comparison of the weekly with the monthly records shows that when the latter only are made, important fluctuations in nitrate-content may pass unnoted. This is particularly noticeable in the curves (not shown) for April and May 1928 for the Y1 plots, and, as will be seen later, the maxima recorded in monthly records are not necessarily true values.

Daily determinations of nitrate-content.—Daily determinations for plot Y1 14 were started early in May 1930, the average rainfall for this month being 6·16 in.; the sampling was done at 7.30 a.m. daily, and the nitrate and moisture determinations carried out as usual. The results are shown in Fig. 4.

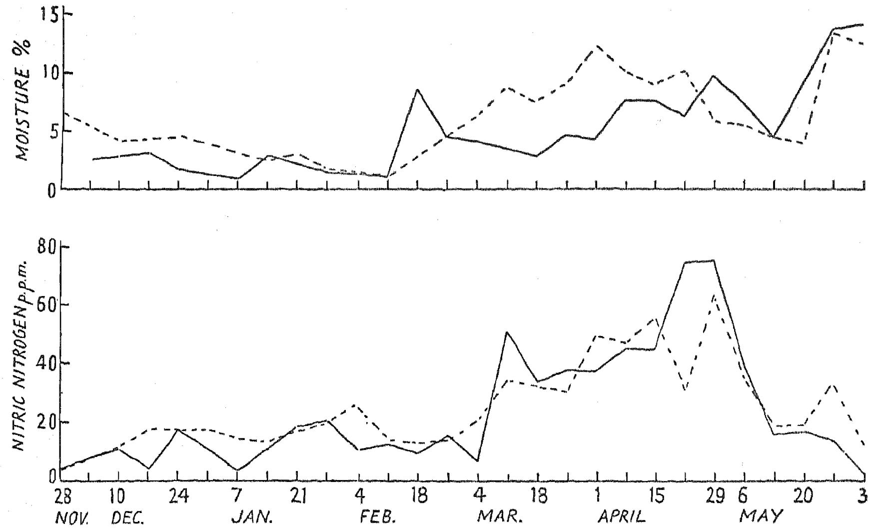

FIG. 3. Weekly nitrate- and moisture-contents for plot Y1 14 from Nov. to June for two years 1927–8 and 1929–30. Solid line, 1927–8; broken line, 1929–30.

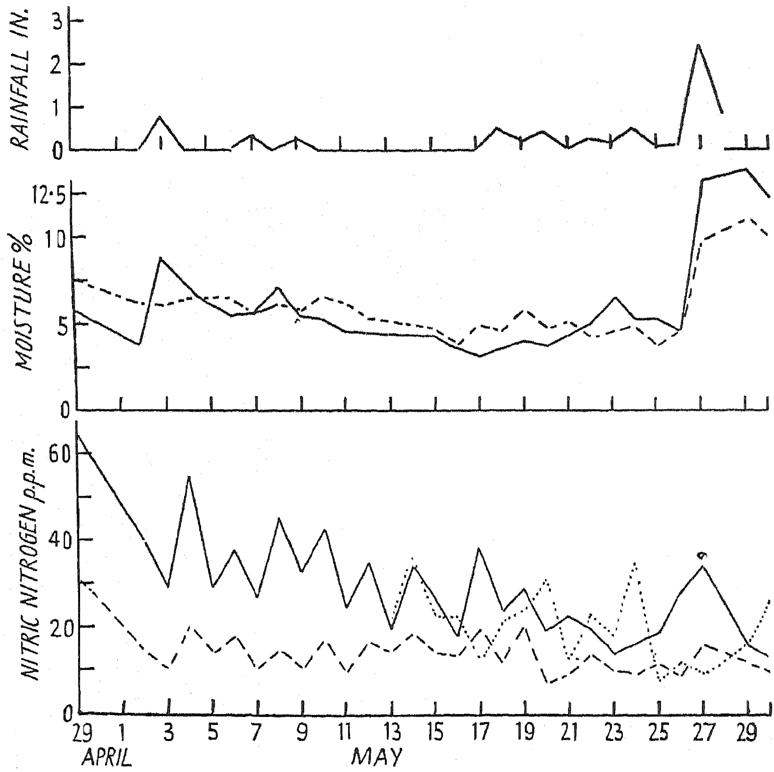

FIG. 4. Daily records of moisture- and nitrate-contents for plot Y1 14, and plot Y1 17, May 1930. Plot 14, depth 1–9 in., solid line; depth 9–15 in., broken line; plot 17, depth 1–9 in., dotted line.

It was unfortunate that May 1930 happened to be abnormally dry, so that sampling became progressively more difficult as the moisture-content decreased up to May 17. The rhythmic fluctuation displayed in the graph is striking; throughout the period the nitric nitrogen alternately increased and decreased almost every day. This alternation is not confined to the surface-soil (1–9 in.), where aeration and other factors are more favourable to nitrification, but it was followed almost exactly, though with a smaller range, in the samples taken from the 9–15 in. layer.

After these records had been continued for a fortnight, a further series of daily records were started on the adjacent plot Y1 17, to see if similar changes were taking place there. On this plot the ridges were very poor; the ground had been very hard when it was ridged up in February, so that it was only possible to obtain the top 1–9 in. sample. The graph shows that the changes on this plot, though not parallel to those on plot Y1 14, are yet very similar to them.

Determinations of nitrate and moisture were also made in Feb. 1930 on a series of daily samples taken from this plot, Y1 14, and also from plot YB 16. The results are shown in Fig. 5. The sampling was started on Jan. 27 and continued until Feb. 24. Plot Y1 14 had been ridged up and a green-manure crop (*Mucuna utilis*) had been dug in eight weeks earlier, whilst on YB 16 a green-manure crop was still growing and the ridges had not been touched. Conditions on YB 16 were thus most unfavourable to nitrification, and consequently the amount of nitrate found was small. If no other data had been available it would have been reasonable to suppose that nitrification had ceased and that the small changes recorded were due to sampling error. An examination of the graph shows that there is a certain amount of parallelism between these records and those for plot Y1 14, and it would appear that the small changes recorded do indicate a very small but real fluctuation. Further, a similar result was obtained on this plot in Feb. 1928, when daily samples were taken for a period of eight days. The fluctuations recorded on plot Y1 14 during Feb. 1930 are similar to those recorded in May 1930, though somewhat smaller. Up to May 27, in spite of the 2·31 in. of rain, which fell 12 hours before the sample was taken on that date, no leaching had taken place (Table 2).

TABLE 2. *Fluctuations in Moisture- and Nitrate-contents of Soil (Plot Y1 14)*

	Top soil 1–9 in.		*Second layer* 9–15 in.	
Date	*Moisture* %	NO_3 p.p.m.	*Moisture* %	NO_3 p.p.m.
May 27, 1930	13·12	33·6	9·59	15·9
May 29, 1930	13·57	14·0	10·88	11·4
May 30, 1930	12·08	12·7	9·8	9·5
June 3, 1930	12·18	12·1	12·13	12·9
June 4, 1930	9·78	6·4	10·68	7·5
June 10, 1030	7·57	7·5	10·55	8·5

The following week, on June 3 after 1·61 in. rain, the moisture-content of the top soil was lower than on May 27, but that of the subsoil was higher. For the first time since May 1 there was more nitrate in the subsoil than in the surface soil, but only by 0·8 p.p.m. On June 4 the relative position was unchanged, there being 1·1 p.p.m. more nitrate in the subsoil. During the next week there was again 1·62 in. rain, though 0·98 in. of this fell on June 6, but on June 10 there was still only 1 p.p.m. more nitrate in the subsoil. It was intended to take another sample on June 11, but heavy rain at about 5 a.m. made conditions unsuitable; in view, however, of the results obtained the week before, i.e. on June 3–4,

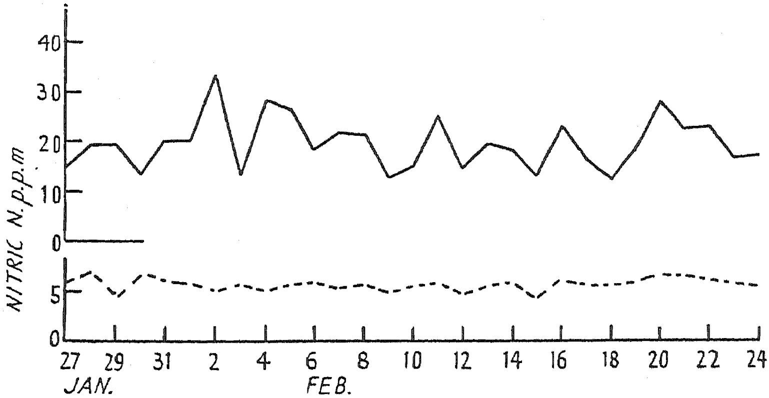

FIG. 5. Daily records of nitrate-content for plots Y1 14 and YB 16, Feb. 1930. Plot 14, solid line; plot 16, broken line.

it is probable that the figures would have been about the same as those for June 10. Thus during a period of seven weeks the nitrate-content had decreased from 64 to 7·5 p.p.m., and during the last three weeks from 33 to 7·5 p.p.m. In the writer's opinion practically none of this loss can be attributed to leaching. Even if it be assumed that during the last three weeks the crop withdrew more nitrate from the subsoil than from the surface soil (an assumption contrary to field observations, since the root-system of the maize plants seemed to be concentrated in the 1–9 in. surface layer) the amount so withdrawn would not be enough to cause any considerable difference between the accumulation in the two layers and so mask a possible loss due to leaching. If, then, in a period of three weeks with 5·5 in. rain, there is a loss in nitrate of 25 p.p.m., practically none of which is due to leaching and little to removal by crop as demonstrated by experiment, it seems that former conclusions regarding losses by leaching will have to be modified.

If these changes recorded from day to day are real, it should be possible, by taking records at still shorter intervals, to trace the changes through 24 hours. On Feb. 24, 1930, samples were taken from Plot Y1 14 at 8.30, 12.30, 16.30, 20.30, on Feb. 25 at 8.30, and from YB 16 at 9.00, 13.00, and 17.00 hours. These results (Fig. 6) show that on both plots the accumulation steadily increased up till 16.30, and that on Y1

14 it subsequently decreased. Then on June 3 samples were again taken from Y1 14 at 4-hourly intervals throughout 24 hours, viz. at 7.30, 11.30, 15.30, 19.30, 23.30, on June 4 at 3.30, and on June 5 at 7.30. On this occasion the nitrates decreased steadily up till 19.30, though the movement between 15.30 and 19.30 was very small, and then increased suddenly between 19.30 and 23.30, again to be followed by a decrease up to 7.30.

In 1927 it was found that the nitrate-accumulation was lower under green manure than under maize crops, and this relationship was recorded

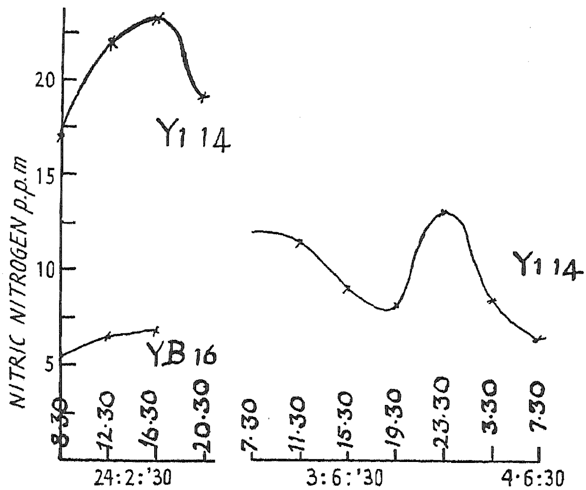

FIG. 6. Four-hourly records of nitrate-content on plots YB 16 and Y1 14, Feb. 24, 1930; and on plot Y1 14 for June 3–4, 1930.

again and again in 1928 and 1929 on plots Y1 19, 17, and 15. This lower accumulation may be due partly to mechanical conditions, for these bean crops soon cover the ground and thus prevent the access of direct sunlight. Moreover, they are not cultivated so much as a corn crop, and consequently a hard crust is liable to form on the surface of the soil, making conditions unfavourable to nitrification. On the other hand, a comparison of the monthly records for the Y1 plots for the period August–December would seem to support both hypotheses, viz. a depression of nitrate-accumulation owing to cropping and to mechanical conditions. On plots 18 and 16, where weeds were allowed to grow after the maize had been harvested, the nitrate-accumulation was lower than on the other plots, and this was particularly well marked during Aug. 1928, when conditions were favourable to nitrification. These results agree with those obtained in three successive years on the 'bush' plot.

In May 1930, on plot Y1 14, it was found that in cropped soil there is a decrease in nitric nitrogen which is not accounted for by removal of nitrates by the crop, or by leaching, and this is in agreement with the results of other workers [4]. Do these crops have a depressing effect on nitrification or nitrate-accumulation, or both?

Various effects of cropping on nitrification and nitrate-accumulation have been noted from time to time [5], but the causes have seldom been satisfactorily explained. Russell [6] suggested that the lower nitrate-production in cropped soils might be caused by some depressing effect of the crop on bacterial activity, or by some process of destruction of nitrates occurring in cropped but not in fallow soils. Referring once more to the results obtained in the daily records for Y1 in May 1930, when the nitrate-accumulation was lowered by over 70 per cent. in the last three weeks, it seems unlikely that the depressing effect of the crop, maize, which is apparently less than that of some other crops, could be responsible for such a marked decline. This marked decline is not an exceptional occurrence, but is recorded year by year at approximately the same period.

Comparison with other countries.—A seasonal fluctuation in nitrate-content has been recorded by several workers. Hall, in South Africa, records a maximum in December corresponding to the summer in the northern hemisphere, though a maximum of 40 p.p.m. for unmanured land is much higher than at Ibadan. Gowda [7] records a maximum in June with a moisture-content of 18 per cent. Again, Batham [8] and Leather [9], in India, recorded a maximum in June in fallow land of 24 lb. per acre. This spring maximum corresponds to our maximum in May and early June, but our second maximum recorded in September is either not recorded in other parts or, if recorded, is not so well marked. Gowda obtained an improvement in the nitrate-content in October following heavy rain in September, and Leather also records an improvement in September to October following a wet period. However, the improvement is much smaller than that recorded in Nigeria, where the second maximum follows a short dry period.

Although the periods of maximum accumulation recorded here agree with the other workers, it must be emphasized that the fluctuations at Ibadan are greater and more rapid than those recorded elsewhere. Batham [10], at Cawnpore, found that the heaviest losses of nitrates occur at the periods of highest rainfall, and that the heavier the rainfall the greater the loss of nitrate; also that the loss is considerably less on cropped land. Although marked losses of nitrate have been recorded synchronizing with heavy rainfall, results have been obtained which show that losses by leaching may not be so heavy as formerly presumed.

Summary

Determinations of the moisture-content and the nitric-nitrogen content in plots receiving different manurial and cultural treatment were carried out for fourteen months during 1927–8; and a similar series was made on another six plots during 24 consecutive months in 1928–30. The latter results confirmed the earlier. Similar weekly records were obtained for six plots from December to May for three consecutive years.

Similar daily records were obtained for periods of one month on two plots in February 1930, and again on two plots in May 1930, and

determinations were made on two plots at 4-hourly intervals for 24 hours.

The monthly records show that the nitrate-content throughout the year is subject to considerable variations, marked by four well-defined periods: (i) low content during the long dry season; (ii) rapid increase in which the accumulation reaches a maximum between April and June; (iii) a minimum low level, which synchronizes with the wettest period of the year, occurs about the end of June to July; (iv) nitrification then becomes more active, resulting in a maximum accumulation in September; (v) the nitrate-content then falls to the low level of the dry season, and the cycle recommences.

The nitrate-content is closely related to the rainfall; this is shown more clearly in the data for the weekly determinations.

The fluctuations in the nitrate-content are generally similar to those observed in other parts of the world, e.g. India. They are, however, more rapid and of greater range than those noted in temperate climates.

The effect of different crops on nitrification has been noted. The nitrate-accumulation in uncultivated 'bush' soil remains at a minimum low level throughout the year.

Good cultivation has a markedly beneficial effect on nitrification.

Pt. II. FLUCTUATIONS OF TOTAL NITROGEN

Monthly determinations of total nitrogen on eight plots of block A3, Moor Plantation, Ibadan, and on five plots of block YB 16, were carried out from Dec. 1926 to Dec. 1927. Some of the results are shown in Fig. 1. Very great changes in the total nitrogen-content of the soils were taking place; increases and corresponding decreases of as much as 500 lb. of nitrogen per acre being recorded in a period of 28 days.

Although the results obtained from one series of plots agreed with those from another series of plots situated in quite a different part of the plantation, further confirmation of these changes was desired. Accordingly similar determinations were carried out on five plots of block Y1 from Oct. 1927 until June 1930, as well as on plot YB 16, and for almost the same period on a plot of 'bush' land near YB 16. These further results were quite similar to, and confirmed those, obtained in 1927.

Although sampling and subsequent handling were so conducted as to ensure a minimum of error, these fluctuations were so large that an estimate was made of the probable error of the result. This was found to be about +50 lb. per acre; therefore if any changes of less than 100 lb. are disregarded, one is still faced with relatively enormous changes in the total-nitrogen content taking place in a comparatively short time.

There was a fairly definite seasonal fluctuation, viz. a tendency for high values to be recorded in the spring, starting with the onset of the rains about April and continuing to May, when conditions appear to be very favourable for bacterial activity and growth generally. These high values may be followed by an immediate decrease and then a further increase and corresponding decrease. Alternately, the high values in

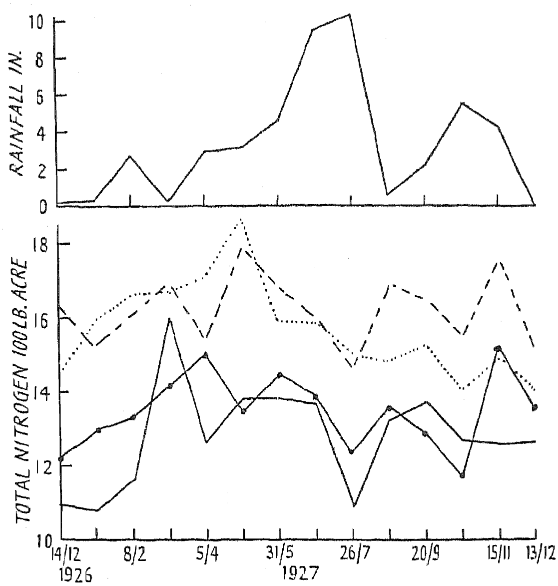

FIG. 1 A. Block A 3. Monthly records of total-nitrogen content for 1926–7 for plots 4, 8, 19, and 21. —— plot 4; · —— · plot 19; – – – plot 8; . . . . . . plot 21. Monthly rainfall above.

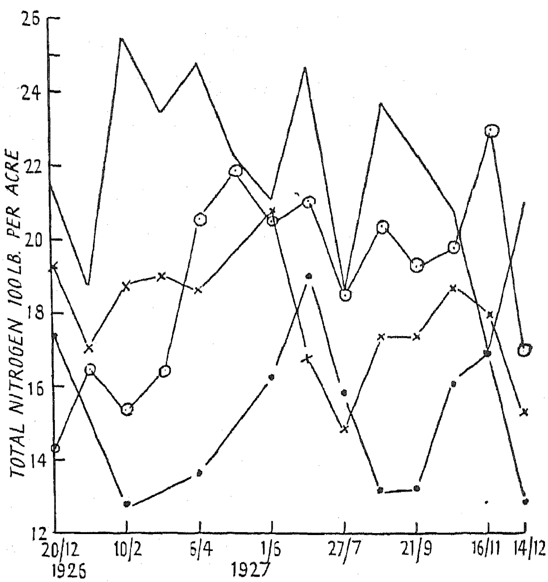

FIG. 1 B. Block YB. Monthly records of total-nitrogen content for 1926–7 for plots 16, 18, and 19, and the adjacent 'bush' plot. —— plot 16; x——x plot 18; ⊙ —— ⊙ plot 19; · —— · 'bush' plot.

spring may be followed by a slower decline until, during the period June–July, low values, usually the lowest for the year, are normally recorded. Subsequently, higher values were again recorded, though they seldom attained the high figures recorded during the 'spring flush'.

Yields and total-nitrogen content.—Comparison of the yields of dry grain and maize (Table 3) with the figures for total-nitrogen content on the Y1 plots shows no apparent connexion between the nitrogen values and the fertility of the plots as judged by the yields for the five years 1924–9.

TABLE 3. *Yields of Dry Grain, Maize (lb. per acre) on 'Y1' Plots*

Plot	*1924*	*1925*	*1926*	*1927*	*1928*	*1929*
14	1,688	900	1,468	1,401	1,456	1,244
15	1,724	912	1,645	1,597	1,718	1,354
16	1,265	620	1,084	990	1,701	1,495
17	1,428	620	1,556	1,412	1,418	1,288
18	1,051	576	1,106	1,240	1,056	1,138
19	1,144	672	1,278	1,412	1,384	1,216
Control	1,225	546	1,243	1,357	1,338	1,190

Thus plot 14, which had the lowest level of nitrogen-values for 1929, did not appear to be losing fertility, whereas plot 18, which was the poorest of these plots, had a comparatively high nitrogen-content and appeared to be gaining fertility.

Advantage was taken of another experiment on green manuring to obtain weekly records of total nitrogen on plot YB 16; these were begun on Aug. 24, 1927, and except for an unavoidable break on Sept. 14, 1927, were continued until Feb. 8, 1928 (20 weeks). In Oct. 1927 another series of weekly determinations of total nitrogen was started in connexion with a cultivation experiment, and records were obtained of the changes occurring in six plots for a period of fifteen weeks. The results of both series showed that the fluctuations during the 7-day period were similar to those previously recorded for a 28-day period. Similar results confirming these earlier records are mentioned later.

On April 18, 1928, a series of weekly determinations of total nitrogen was started in connexion with another cultivation experiment, and, except for a break on Aug. 29, 1928, was continued to Dec. 1928 (Fig. 2). The fluctuations were more marked on the cultivated plots than on the uncultivated, and although the trend of the changes was the same in all plots, they were rather more uniform on the cultivated plots. Thus the weekly determinations showed that the maxima and minima recorded in the monthly determinations were not true maxima and minima, but only points showing the balance of the gains and losses taking place during each interval of four weeks.

Daily records of total nitrogen.—In Feb. 1928 the results of a preliminary experiment, in which daily determinations of total nitrogen were made for one week, showed that quite big daily changes might occur. In 1930 it was decided to obtain further daily records to ascertain

if the sudden changes that took place from week to week could be followed from day to day.

On Jan. 27, 1930, daily sampling was started on plots YB 16 and Y1 14 and continued until Feb. 24. The method of sampling is described in Appendix II. The results are shown in Fig. 3. In the graph the dates for the 1928 determinations have been displaced so as to antedate them by three days.

These graphs show that marked changes in the total-nitrogen content occurred in these soils. There was also a considerable degree of uniformity, as shown by the parallelism of the graphs, in the changes taking

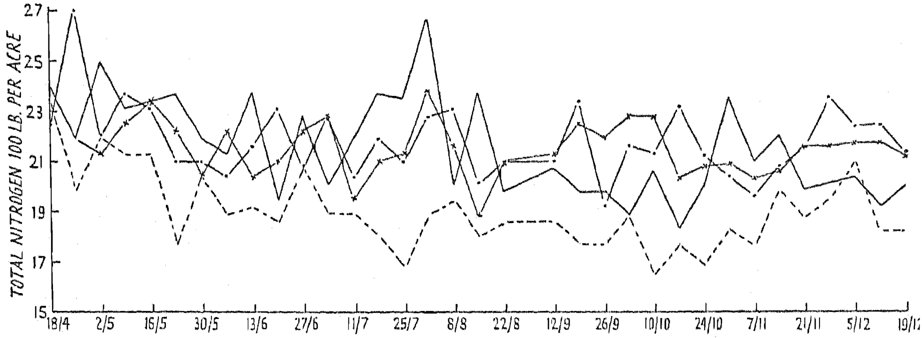

FIG. 2. Block Z1. Cultivation experiment April–Dec. 1928, plots 2 and 10 cultivated; plots 3 and 11 controls. · —— · plot 2; - - - - plot 10; x —— x plot 3; —— plot 11.

place on the two plots, which are about a mile apart. During the first ten days the parallelism between the two graphs was remarkable. The changes which occurred on YB 16 in 1928 were almost exactly parallel to those recorded in 1930. Although the cropping and cultural treatments were so different, the graphs are so uniform that it is evident that at this period these factors could not have influenced the changes recorded. Very big changes in the total-nitrogen content took place, increases and subsequent decreases of as much as 500 lb. per acre occurring in a few days. The parallelism of the graphs for the different plots in different parts of the farm in different years seems to indicate that the changes were real.

In view of the daily variation recorded, it was decided to make observations at 4-hourly intervals, to see if the variation recorded in 24 hours was due to a steady movement, or alternatively, if it were also subject to periodicity. These results are shown in Table 4.

On Feb. 24 there was an increase in all plots in the middle of the day, followed by a decrease at 16.30, which on plot Y1 was again followed by an increase. On June 3 the changes recorded followed a parallel course; they were quite small, and if no other data had been available, might have been ascribed to sampling errors, but in view of the strictly parallel changes recorded in February on the same plot, and the similar though larger change on YB 16, they are held to be real, and to have indicated a regular periodicity throughout the day.

As with the daily determinations of nitric nitrogen, the daily records

of the changes in total nitrogen enable one to see the longer-interval records in a truer perspective: thus the weekly records give a reasonably correct account of the changes taking place during any fairly short period, e.g. a few weeks, and the monthly records give a much broader view of the variations, showing to what extent seasonal changes, if any, may take place.

TABLE 4

Feb. 24, 1930			*June 3, 1930*	
Time	*YB 16 Total N*	*Y1 14 lb. per acre*	*Time*	*Y1 14 Total N lb. per acre*
8·30	..	1,647	7·30	1,656
9·0	1,917	..	11·30	1,767
12·30	..	1,770	15·30	1,713
13·30	2,175	..	19·30	1,752
16·30	..	1,674	23·30	1,716
17·30	1,916	..	June 4	
20·30	..	1,734	3·30	1,686
Feb. 25				
3·30	..	1,620	7·30	1,734

Considering the monthly records in this new light, it will be noticed that seasonal variations in total nitrogen were not so well marked as those of nitric nitrogen, though in both cases there was a marked increase and subsequent decrease in the early months of the year. This suggests that variation in both nitric and total nitrogen may be influenced by the same cause. This seasonal influence seems to be more marked in the uncultivated 'bush' soil. The records for four years on this plot, for the period January to April, show that total nitrogen tends to increase steadily as the year advances, and culminates, according to the records for 1927–8, in a maximum about June. Now the observations made in 1927 on the rate of growth of vegetation on this plot, indicate that there was a marked increase of the rate in June, i.e. about the same time as the seasonal increase in total nitrogen approached its maximum. This coincidence does not seem to have been entirely fortuitous.

A comparison of the graphs for the nitrate-content and total-nitrogen content of plot Y1 14 for Feb. 1930 indicates that during this period the changes recorded were in harmony; the graphs are parallel.

The possible factors which might affect the total-nitrogen content of the soil are: (*a*) and (*b*) climate, and (*c*) green manure.

(*a*) The regular periodicity in the fluctuations from day to day did not appear to be affected by external factors, such as climate and cropping, though both these factors might influence the range of the periodicity.

(*b*) The changes in nitric nitrogen were as a rule small compared with those of total nitrogen, and the effect of the withdrawal of nitrate by the crop was also insignificant, an average crop of maize (grain only) taking about 30 lb. nitrogen.

(*c*) On many of these plots crops of leguminous green manures have been grown and dug in. The average weight of a crop of *Mucuna utilis*,

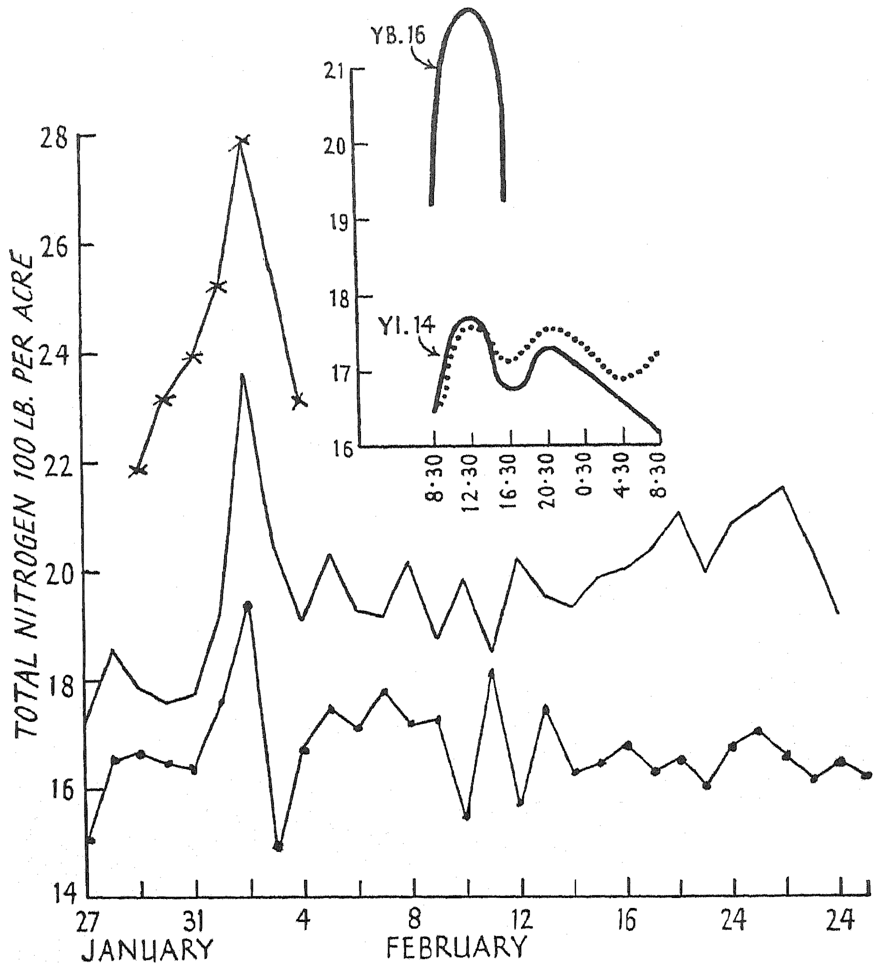

FIG. 3. Daily records of total-nitrogen content for plots YB 16 and Y1 14 from Jan. 27 to Feb. 24, 1930; also for plot YB 16 for Feb. 1–7, 1928. The graph for the latter record is antedated by three days in its position. —— YB 16; · —— · Y1 14; x —— x YB 16, 1928.

Inset. Four-hourly records for plots YB 16 and Y1 14 on Feb. 24, 1930, shown in solid line, and for Y1 14 for June 3–4, 1930, shown by dotted line.

which gives rather a heavier crop than *Dolichos lablab*, at the stage when it is dug in, is about 5 tons per acre, and it contains about 60 lb. of nitrogen. Assuming that the whole of this nitrogen is obtained from the air, then a 5-ton crop of *Mucuna* would add only about 60 lb. of nitrogen per acre: a small amount compared with the changes in total nitrogen. Some of this nitrogen, too, only becomes available slowly as the material is decomposed.

Thus these changes are well defined, irrespective of external factors, but they are too large to be explained by the action of known organisms under field conditions.

Discussion

The work on nitrogen-fixation in the field that has been done in India has a direct bearing on the results here recorded. Following laboratory experiments made to ascertain the optimum conditions favourable to nitrogen-fixation by Azotobacter [11], field experiments were started at Pusa, by Wilsdon and Ali [12], who, in a paper published in 1922, stated that very large increases in the total nitrogen of field soils, over 100 per cent. on the original nitrogen-content of the soil, had been recorded in 1916. The fixation was markedly subject to seasonal influences, but the large increases recorded in 1916 were not obtained in subsequent years, although quite substantial increases were found. They also observed that denitrification took place after a period of maximum fixation. Later, Lander and Ali [13] recorded an increase of 58·4 per cent. over the original nitrogen-content in a month, and that denitrification took place after fixation.

The extent and rapidity of the changes here recorded are, as shown by the monthly records, greater than those reported in India.

Judging by the monthly records of nitrate-content of the plots, there is no particular indication that the fixed nitrogen becomes available to the plant.

Summary

Determinations of total nitrogen were made on several plots at monthly intervals for a period of three years. Determinations were also made at weekly intervals on one plot for nine consecutive months, and on three plots for the period Dec.–May for four years. On two plots determinations were made every day for a period of one month, and on one plot determinations were made on samples taken every 4 hours for 24 hours. It was found that in these soils the total-nitrogen content fluctuated continually, even from day to day. The range of the fluctuations was marked by a seasonal influence in the spring, and it may also be affected by cropping and cultural operations. There does not appear to be any direct connexion between the level of the total-nitrogen content throughout the year and the fertility of the soil.

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APPENDIX I

Note on method of sampling and technique.—All samples were taken with a steel auger 18 in. long and 2 in. in diameter. Normally six cores were taken from each plot to form a composite sample, but in 1927 the samples from the plots on block A3 were composites of three cores, whilst in 1929–30 the samples from plot YB 16 were composites of twelve cores. The borings were equally spaced throughout the length of the plot and taken from the same ridges at each sampling. The samples were dried and prepared for analysis in the usual way.

Determinations of moisture and nitrate.—A small 4-oz. clean, dry glass bottle, fitted with a rubber stopper, was provided for each plot. From alternate cores of each sample a small portion of the soil from a depth of 4 to 5 in. was removed from the auger, quickly transferred to the bottle, and the cork firmly inserted; thus about 3 oz. of soil was obtained from each plot. After mixing, about 5 to 10 gm. of each sample were weighed out, and dried at 100° C. The moisture-content was calculated as a percentage on the oven-dry weight.

Nitrates were determined by the phenol-disulphonic-acid method, and the total nitrogen by the Gunning-Kjeldahl method. The total-nitrogen determinations are the result of replicate analyses: on occasions there was some difficulty in obtaining satisfactory duplicates and a further series had then to be run; the error allowed was 0·0005 per cent.

Sampling.—That the method of sampling is satisfactory is well shown by the remarkably good agreement in the moisture and particularly the nitrate determinations, where normally a fairly high coefficient of variability might be expected.

APPENDIX II

Sampling Error.—The normal sample consisted of a composite of 6 samples taken by means of a soil auger, but on the A3 plots composites of only 3 samples were taken.

To determine the sampling error 6 samples of 3 composites were obtained from plot A3, and 6 samples of 6 composites from plot YB 16. The following data were obtained:

PLOT A3 16.

Total N per cent.

0·0441
0·0435
0·0462
0·0471
0·0433
0·0425

Mean $= 0·0445 \pm 0·005 = 1335 \pm 15$ lb.
$\sigma = 0·0016 \pm 0·0003 = 48 \pm 9$ lb.
P.E. of mean = 1·0 per cent.
Probable error of a single composite sample
$= 0·6745 \times \sigma = 0·0011 = \pm 33$ lb.

PLOT YB 16.

Total N per cent.

0·0896
0·0863
0·0845
0·0903
0·0844
0·0861

Mean $= 0·0869 \pm ·0006$
$\sigma = 0·0023 \pm 0·0004 = 69 \pm 12$ lb.
P.E. of mean = 0·71 per cent.
Probable error of a single composite sample
$= 0·6745 \times \sigma = 0·0015 = 469$ lb.

The weight of soil was taken as 3,000,000 lb. per acre.

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SOIL EROSION IN THE COLONIAL EMPIRE

SIR FRANK STOCKDALE

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THE Colonial Empire is far flung and its several dependencies present a great variety of conditions of soil and climate. In certain colonies the land is comparatively flat, and in others it is mountainous or considerably broken with hill ranges. The greater part of the Colonial Empire is within the tropics, but some dependencies are in the tropical rain-belt with its high forests and heavy rainfall, whilst others are in areas of low rainfall with lengthy periods of extreme drought. In all tropical countries, even when the total rainfall is low, torrential rain-storms occur from time to time, and on such occasions soil erosion is bound to occur if the natural vegetation has been interfered with.

The last fifty years has seen a marked development in tropical agriculture. Extensive estate industries, such as tea, rubber, coffee and cacao, have been created, and the production of cacao, cotton, &c., has much expanded as the result of the efforts of the increasing indigenous populations. Considerable areas of forest have been destroyed and replaced by cultivations covering millions of acres, and large sections of grass lands have been brought into cultivation under economic crops. The increasing populations have also cleared large areas of forest-clad lands for the production of additional food requirements, and have exploited lands with grass-cover for a similar purpose.

In the tropical rain-belt, with its luxuriant forest-cover, there is normally very little erosion, despite the high rainfall. The forest vegetation breaks the violence of the rainfall and assists the absorptive capacity of the soil by means of the fissures caused by root-penetration and the highly absorptive layer of leaves and debris deposited on the soil surface. Remove the forest-growth and the soil is exposed to the beating effect of rain and to the effects of the sun. The surface-layer of forest litter soon decomposes or disappears, the pore-spaces in the soil are soon silted up by the washing into them of the finer soil particles, and the land is compacted by the force of the rainfall. In consequence, the high absorptive capacity of forest-clad soil is quickly lost. It is quite common to see excellent forest soils lose their layer of organic matter and their tilth within 12 to 24 months from the clearing of the forest, and in certain localities erosion may begin within a few months from the time the forest is felled.

Grass-covered lands also absorb quite large quantities of water if the cover is a good one and the herbage is not too short. In low-rainfall areas, a grass-cover may be as effective a cover as forest because of the lower evaporation, but opinions are still divided on this issue. Some interesting data have been secured in the Union of South Africa, and a certain measure of confirmation of the South African conclusions is forthcoming from Tanganyika. Under grass there is less drying out of a soil—particularly in its deeper layers—than under forest, but when

land is forest-covered it has a higher absorptive capacity as the result of deeper root-penetration and the channels which follow root-decay. The actual distribution of the rainfall is, therefore, of importance when considering the relative value of forest- and grass-cover, but generally it may be accepted that the order of protective value of vegetation is (1) forest, (2) bush or scrub, (3) grass.

The problem of soil erosion in the Colonial Empire is not a new one, but it must be recognized that the rate of erosion has been greatly accelerated by the increased development in recent years, and is assuming serious proportions in certain parts of the East African dependencies. Here it is found that erosion is worst when the rainfall is relatively low and the rainy season is heralded by numbers of heavy rain-storms. When they occur the land is as dry as dust with a poor cover of vegetation. The absorptive capacity of such soils is low and considerable quantities of top soil are washed away before it becomes thoroughly wetted. When the rainfall is more evenly distributed, even though it may be more heavy, erosion is not so bad as in areas where lengthy dry periods occur. Lands under conditions of an evenly distributed rainfall also retain a vegetative cover better than do lands which are liable to periods of drought.

Some soils erode more severely than others. The calcareous soils of Jamaica, for example, do not erode at all seriously, whilst those derived from schists in the Blue Mountain Range readily are washed away with a fall of rain. Soils in the drier areas of Kenya with a high silica ratio erode more rapidly than the loams to be found in the wetter areas. The lighter sandy lands of St. Vincent also erode more easily than do the heavier lands of its neighbouring island Grenada.

Certain loams have, in fact, a higher absorptive capacity than sands, and it is known that soils which are inclined to swell and become sticky when they are wetted erode more rapidly than soils which 'walk clean' after rains. Friable soils with a low silica ratio are not usually subject to a high degree of erosion, whilst some soils, such as those of Nyasaland, are liable to compact and form sub-soil pans and crusts from which the top soils are readily washed away.

In pastoral areas overtrampling by stock is often as responsible for erosion as overgrazing, especially during the dry season and in the neighbourhood of watering places. This trampling of dry soil, especially when sheep and goats are numerous, reduces it to powder, which is either blown away by the wind or washed away by the first rains from the layers of consolidated soil below it. The availability of water-supplies is of importance in pastoral areas as the movement of stock to and from water is often a prominent causal factor in erosion. Where water-supplies are poor, concentrations of stock occur around them, and when the grasses 'spring' after the first rains they are ravenously devoured. No satisfactory growth of grass is permitted to take place, and there is in consequence nothing to bind together the loose powdery soil and to prevent it from being eroded by either wind or water. In certain areas there is definite overstocking. This occurs in some of the East African territories in certain areas, but it is possible that the damage may

often be mitigated by an increase of water-supplies and by the adoption of controlled grazing.

Basutoland offers an outstanding example of unchecked soil erosion. The position is clearly set out in Sir Alan Pim's report, where it is recorded that the primary cause was overgrazing, leading to the destruction of the vegetation which holds the very friable soil together. Steps have been taken to adopt control measures and the position is being improved. The experience gained in Basutoland should be of value to those who are faced with problems of a similar character in East Africa.

In Ceylon, the alienation of Crown Lands above the 5,000 ft. contour has been prohibited for over thirty years, and in some of the West Indies similar legislation is in force. In St. Vincent, for example, all Crown Lands of 1,000 ft. or over have been protected since 1912 from any act which would be prejudicial to the conservation of the forests growing on them, whilst in St. Lucia lands of 1,500 ft. and over, and in Montserrat at heights ranging from 700 to 1,000 ft., have been similarly protected since 1916 and 1932, respectively.

This system of protecting the forest-cover at the higher altitudes has much to commend it in the hilly wet tropics, but it is not really effective unless it is strengthened by measures designed to protect the catchments and springs of the principal streams, and to compel, as has been accepted in Java, that where sloping forest lands are cleared for agricultural purposes there should be established adequate anti-erosion measures before planting begins.

Such measures must be framed with due regard to the soil type, the rainfall and its distribution, the slope of the land and the aspect of the slope. They should aim at checking the velocity of the 'run-off' and, if possible, at increasing the absorptive capacity of the soil. In the state of nature an equilibrium becomes established so far as run-off is concerned, but with the arrival of man and his domestic animals this balance is upset, gradually at first, but ultimately at an ever-increasing rate as the population and numbers of stock increase and developmental activities expand.

During the past few years there has been an awakening throughout the Colonial Empire to the losses which are being occasioned by soil erosion and to the threat of danger for the future. The position at the present time is briefly reviewed below.

West African Dependencies

Little or no special attention has been given to soil erosion in West Africa. Over vast stretches the land is gently undulating and the individual farming operations are on a small scale. Many of the methods of cultivation are based upon custom and are designed to check erosion. This applies particularly to the Southern Provinces of *Nigeria*. The land is often thrown up into mounds, frequently with the inversion of the top layer of soil, so that the weed- or grass-vegetation which it carries is buried. This helps to hold the mound together and the presence of these mounds checks the flow of rain-water and allows it to soak in. Throughout West Africa in the yam-growing areas the system is much

the same, but in some places ridges and furrows are made and these are so broken that run-off is checked. The local hoes are specially adapted for making mounds or ridges and for inverting the top soil. Where the rainfall is heavy the mounds or ridges are quite large and their preparation involves much labour.

Mixed cultivation is also the rule, and where it is practised there is rarely any lengthy period when the land is devoid of any form of vegetation. In the drier areas towards the north, however, the ridges are smaller, and during the dry season there is little vegetation on the land.

The Department of Agriculture in Nigeria has found, as the result of experimental tests, that the system of mound- or ridge-cultivation is sound and that in the Southern Provinces there is little erosion provided that vegetation is continuously kept on the land by systems of mixed cultivation or rotations. In the Northern Provinces, the position is not so satisfactory, but generally speaking there is little erosion resulting from agricultural operations except where populations are concentrated and stock numbers are high. Where ploughing has been introduced care has been taken to introduce only the double mould-board pattern so that ridge-and-furrow cultivation is continued. Ploughing also is only used where mixed farming is practised and farmyard manure is prepared for use on the land.

In the extreme north, increases in the population and their stock are resulting in encroachments on the scanty forest-cover and Prof. R. Stebbing has drawn attention to what has frequently been referred to as the advance of the Sahara into Nigeria. On examination it has been found that it is not a case of encroachment by drifting sand from the Sahara, as had so often been mistakenly supposed, but one of soil degradation, which has led to the establishment of desert conditions in areas previously protected by vegetation. Repeated use of the land for agricultural purposes has reduced the density of the vegetation, and grazing by large numbers of stock has helped in the destruction. Prof. R. Stebbing, referring to the increase of population in a recent paper, states: 'Some change in the methods of agriculture would appear imperative if a farther migration to the south is not imposed upon it. Here the agricultural use of the forest is accompanied by the browsing and grazing of large herds of cattle and flocks of sheep and goats. Here again the numbers of animals are said to have greatly increased during the last two decades.' The desert conditions are being developed *in situ*, and a special officer has been entrusted with the task of co-ordinating the measures needed to prevent a spread of the damage. A certain amount of erosion both by water and wind occurs in the area, but this is not as responsible for the damage as the general soil degradation which is taking place.

The general position in the *Gold Coast* is not as satisfactory as that in Nigeria. Vast areas of high rain-forest have been cleared for food farms and for cacao cultivation. It is estimated that there are over a million acres under cacao, and although no special measures have been taken to prevent erosion, the losses have not been so great as might have been expected, owing to the stumps of forest trees having been left in

the clearings, and to the establishment of the cacao in a mixed plant-cover of food crops. Many of these crops are grown on mounds, and where this system of cultivation is practised the soil losses from erosion are not excessive. There have been, however, considerable areas of forest cleared for cultivating maize, which is the staple food crop in the Gold Coast. In many of these areas erosion has developed and it is now common to see large areas of land devoid of its surface-layer. This is particularly noticeable in the coastal areas where the population is dense and a fair amount of erosion is also noticeable in areas where the population has increased considerably during the past twenty years.

In the Northern Territories of the Gold Coast stock numbers have been increasing since rinderpest has been controlled. The Department of Animal Health is endeavouring to demonstrate the value of cassava roots and hay as food for cattle during the dry season, whilst the Department of Agriculture is testing the practicability of introducing a system of mixed farming in those areas where the population is fairly dense. Under the existing system much of the land is being degraded and a certain measure of erosion is to be noticed.

In *Sierra Leone*, soil erosion has been responsible for serious loss of fertile top soils from the hills of the Colony behind Freetown. Many coffee and other cultivations have seriously deteriorated because no attempts have been made to terrace the land with a view to preventing soil wash under the heavy rainfall of the area. Attempts are shortly to be made to resuscitate some of these cultivations and to encourage the establishment of terraces and other measures designed to check erosion.

In the Protectorate the position is not so serious, for here the chief agricultural problem on the high lands is the maintenance of soil fertility. Shifting cultivation is generally practised for the production of hill rice, millets, and other food crops, and land which was formerly under good forest is now covered only with bush-growth and in many areas with a poor cover of grass. There is naturally a certain measure of soil washed into the swampy valleys which intersect the undulating hills, but increasing attention is now being given to the cultivation of rice in these swamps and it is expected that the pressure on the high lands will thereby be reduced.

In the *Gambia*, the agricultural methods are based on the ridge-and-furrow system, and a special hand-implement has been devised for working the light sandy soils and for inverting the top soil layer when the ridges are being made. In consequence soil erosion is not serious, except occasionally on the edges of the creeks.

East African Dependencies

In the East African Dependencies the picture is very different. Uncontrolled erosion is visible in many places and gully-erosion at its worst can frequently be seen. Hill slopes formerly fertile are becoming barren wastes, and plains, which were formerly grass-covered, are now being ruined.

In *Northern Rhodesia*, the earlier European pioneers paid little or no attention to soil erosion on the lands which they brought into maize or tobacco cultivations. In recent years, however, a certain amount of

ridge-terracing has been introduced. The Ecological Survey has recently shown that there have been marked changes in the agricultural systems used in the Reserves, especially in those nearest to the European areas. The older and traditional native systems of agriculture consisted of small farms of 2–3 acres in extent. These were cut out of the bush, with tree stumps left here and there, and the formation of mounds for certain of the crops grown was the common practice. Within the past twenty years ploughs have been introduced, and during this period there has been a piecemeal departure from the traditional systems of agriculture towards an imitation of the methods of European farmers. Areas of 10–20 acres have been cleared and stumps removed so that the land may be ploughed. Often the ploughing has been done up and down the slope, whilst maize and the larger millets have taken the place of finger millet, and sweet potatoes, instead of being planted on mounds, have been grown on the flat. Ploughing has tended to increase the run-off and there have been no tree stumps or mounds to check the flow of water. Soil erosion is, in consequence, becoming more and more serious and unless a change can be effected serious damage must result. It is not to be expected that a reversion to the traditional methods of the past will be either possible or practicable, and the efforts of the Department of Agriculture are directed towards demonstrating the importance of anti-erosion measures, ridge-and-furrow cultivation along the contours, and mixed farming.

In certain of the pastoral areas of the territory, increasing numbers of stock are giving rise to a greater destruction of forest-growth than is desirable, and some overgrazing and overtrampling of pasturage is noticeable. With an increase of the water-supplies in the native stock areas and a better organization of stock marketing a considerable improvement could be effected.

In *Nyasaland* increased attention has been given of late to the problem of soil erosion. The earlier records show that the inhabitants of the country lived almost entirely in the alluvial valleys and plains bordering on the rivers and lakes. At that time the plains were reputed to be extraordinarily fertile. The hills and mountain ranges were forest-covered and many of the streams from the hills ran throughout the year. Areas at present sparsely populated, with little or no water in the streams, are reported to have been well wooded fifty years ago, with streams flowing for practically the whole year round. Large forests have given way to open woodland or orchard country consisting of tall grass with scattered small trees, and this orchard country, in its turn, is giving place in certain areas to pure grassland. In fact, treeless plains now extend over considerable areas of the country and mountains and hills stand up as large masses of bare rock. Important waterways, such as the Shire, have silted up and much of the earlier rich alluvium has been lost. It has been computed that many of the highland areas are losing soil at the rate of a quarter-inch layer per annum, whilst bush fires, which rage at the end of the dry season, are contributory to the destruction.

Such is the picture of the changes which have taken place in Nyasaland, and that grave concern is felt is not surprising. The soils of Nyasaland

are very friable and, in consequence, erode easily. Sub-soil pans and crusts are common, and these in their turn encourage erosion as the absorption capacity of the soil is reduced.

In the tea cultivations greater attention is being given to the growth of cover crops, and the adoption of anti-erosion measures is becoming general. On tobacco and cotton lands a system of broad-based contour-ridges, graded according to the slope of the land, has become common. The Government has also adopted special legislation (Ord. No. 15 of 1932) to control bush fires, and has seconded a Forest Officer for special soil erosion duties. His chief work will be in connexion with the development programmes for the Central and Northern Provinces, where it is hoped to introduce rational systems of land-usage with clearly defined agricultural and forest policies. The recent agricultural survey has emphasized the necessity for care in the development of these areas, so that future generations in Nyasaland will not be faced with large losses of valuable land and an inevitable costly expenditure on anti-erosion works.

Passing from Nyasaland into *Tanganyika*, the damage which can be caused by soil erosion can clearly be seen. Over considerable areas of the Lake Province, wind-erosion has caused much damage for a number of years, whilst in parts of Central Tanganyika gully-erosion at its worst is frequent. In yet other areas, concentrations of stock have been responsible for overgrazing and for excessive trampling.

Much attention has been given to the problem in recent years. A standing committee, on which the Agricultural, Veterinary, Geological, Forestry, Public Works, and Railway Departments were represented, was set up under the chairmanship of the Director of the East African Agricultural Research Station at Amani to study the problem and to make recommendations for work to be undertaken. The problem is being approached in each area according to the form in which erosion is attacking the countryside, and the work has been entrusted to the Heads of the Agricultural, Veterinary and Forest Departments acting in co-operation with the Administration. Active steps are being taken to deal with the problem by means of a multitude of minor operations, including the planting of trees to check wind-erosion, contour-ridging and terracing, contour hedge-planting, the damming of gullies, &c. These works are being carried out by local endeavour under local stimulus and supervision.

In the south, around Iringa, efforts are being made to control the annual burning of pastures, schemes of reafforestation and of planting wind-breaks have been undertaken by the Native Authorities, control of wood-cutting has been imposed and steps taken to check the frequency of forest fires. Contour-ridging and the planting of contour-hedges on cultivated lands are being encouraged.

In the Lake Province, hundreds of miles of wind-breaks have already been established, and the Department of Agriculture has greatly assisted the development of contour-ridging and terracing. Mixed farming is being encouraged, and the planting of rows of sisal around the boundaries of farms is becoming general. Grazing reserves have been set aside for stock, increased water-supplies for stock are being developed,

and the low-lying valley lands are being developed for grazing during the dry season. Settlements in new lands reclaimed from tsetse are also being established to relieve the badly congested areas.

Around Dodoma, the principal cause of erosion is the trampling of the pasturage by stock moving to and from the scanty water-supplies. Watering places for stock are therefore being increased and improved in this area. It has also been demonstrated at Dodoma and elsewhere that, if overgrazed or overtrampled grazings are rested for a year or two, the vegetation quickly recovers and sheet- and gully-erosion are checked.

Efforts are being made to establish settlements in the plains so as to allow the upland pastures a chance to recover. In both the Central and Northern Provinces of Tanganyika, concentrations of population are to be found on the hills. In the times of raids there were definite migrations to the hills for safety, and permanent settlements were established thereon. In recent years, the Department of Agriculture has carried out valuable demonstrations of anti-erosion measures in the hill districts, and the majority of the Native Authorities have passed rules making anti-erosion measures compulsory. Clearing or cultivation on steep slopes is prohibited, contour ridges or hedges have to be provided, and the cutting of wood and grazing of livestock in controlled riverside areas have been prohibited. The anti-erosion legislation by the Chiefs is an important step forward; it has the full support of the Chiefs, the elders, and the people themselves. It is a tribute to the work of the officers and instructors of the Department of Agriculture in their efforts to educate public opinion and to interest the native authorities in the preservation of their lands from ruin. The movement of hill tribes to the plains is also being encouraged, but this movement can only be gradual, because when the hill people take up habitation on the plains they often suffer severely from malaria, and they have a real fear of the damage to crops on the plains by game.

The Department of Agriculture has, however, recently undertaken the organization of a number of settlement schemes, each based upon an experimental station and an instructional centre. Careful attention is being given in all these settlements to the adoption of anti-erosion measures and to the encouragement of mixed farming.

Anti-erosion propaganda is also being carried on through the schools.

Much useful work is being done in Tanganyika, and if the present measures are prosecuted with energy a great improvement in the position will be effected within the next ten years. There is ample land available, as four-fifths of the territory is still infested with tsetse, and it has been demonstrated during the past few years that land can be won from tsetse either for organized settlement or for the extension of grazing for stock.

An investigation of water-supplies has also been undertaken, and the possibility of extending irrigation has been studied. On the slopes of Kilimanjaro much erosion is still caused by inefficient irrigation, and if an improvement equivalent to that which has taken place during the past five years in the coffee-growing areas of the mountain can be effected, the position will be greatly improved.

In *Uganda* the soil-erosion problem has not been given such wide-

spread attention as it has been in Tanganyika. The damage which might be caused by erosion became evident when a certain area of the Serere Experiment Station in the Eastern Province was found to have suffered so severely from sheet-erosion that after twenty years little surface-soil was left. The area had been eroded to the sub-soil, which was practically unproductive despite the efforts made to maintain fertility by the use of green manures. This example forcibly directed the attention of the Department of Agriculture to the need of encouraging agricultural methods designed to ensure the maintenance of soil fertility. Experimental tests have demonstrated that soil fertility can be maintained in the elephant-grass country by the rotation of cultivations with resting periods of two to three years under elephant grass. It has also been found that coffee cultivations can be saved from soil erosion if mulches of elephant grass or banana trash are used on the contours. An extension of this practice is gradually taking place, but there are still many coffee cultivations on the hill slopes in which anti-erosion measures have not yet been taken. There are also in the Buganda Province areas of hill lands which have been put into cotton with the resultant loss of fertile top soil.

In the Eastern Province, where the dry season is often very severe, rotations of cultivation with resting periods under grass are being tried, but it is probable that a system of mixed farming and broad-base contour-ridges will have to be introduced if the sheet-erosion from which considerable areas of the Province suffer is to be checked.

An Agricultural Survey Committee was established in 1935 to deal with soil-deterioration problems, and to analyse the *mutala* surveys which were being undertaken. These surveys were designed to secure data about the social life of the people, their dietary, and the acreages under crop during the long and short rains. Data concerning the average size of the holdings, the rotations practised, and the areas available for arable cultivation and for pasturage, have been secured. Much information of value has been accumulated, and in certain densely populated areas in the Eastern Province sheet-erosion has been found to be serious. Its development has been encouraged by the use of ploughs, without the adoption of mixed farming, and by a reduction of the resting-period when the land is under grass. Erosion often begins from the rocky outcrops, which occur frequently in the Province, as it is from these that water-flow starts during the tempestuous storms that commonly occur with the break of the rains. Definite anti-erosion measures will have to be adopted if the sheet-erosion which is taking place is to be checked, and mixed farming will have to be introduced in those areas where there is an insufficient amount of land available for the necessary resting-periods between cultivations.

A soil-erosion inquiry has been made by the heads of the Geological and Forest Departments, and their report has recently been issued. Attention is drawn to the serious erosion which is taking place in the north of Uganda, and it is clear that large areas will have to be retired into reserved forest if the grazing and agricultural lands are to be saved from ruin. Attention is drawn to the extent of the sheet-erosion in the Eastern Province. Losses are also occurring in the Buganda Province and elsewhere where cotton and coffee cultivations are being carried out

on hill slopes without the adoption of anti-erosion measures, such as contour-ridges, strip-cropping, contour-mulchings, &c. In certain areas, overgrazing is causing some trouble, and greater attention will have to be given to the spread of the stock population by an increase of water-supplies and to the introduction of rotational grazing.

Except in the north of Uganda little gully-erosion is to be seen, but danger from the insidious sheet-erosion exists. Its widespread effects are only now being realized, and unless definite action is taken soil deterioration will progress and lower crop-yields result. Cotton yields are already falling in certain areas of the Buganda Province, and there has recently been some loss of quality. These effects are probably the result of soil deterioration and much of this, especially in the hilly areas, is due to sheet-erosion.

In *Kenya* the position is much more serious. It is the most important land problem with which the country is faced at the present time. It is impossible to exaggerate the gravity of the problem. There is little doubt that soil erosion has been extending in recent years in some of the Reserves, and whilst reconditioning has been started in certain areas and the results which have been obtained show that erosion can be checked, measures of wider application will have to be undertaken without delay. It is possible to save the greater part of the areas affected if prompt action is taken.

In the European areas in the highlands, much has been done in the past few years. Broad-base contour-ridges have been made over extensive areas and strips of grass or other close-growing vegetation have been established. In coffee cultivations, greater attention has been given to the use of cover crops, shade, and box-terraces. The Agricultural and Land Bank is playing an important part in the development of anti-erosion measures on European holdings, as general advances are not issued to proprietors who do not adopt adequate measures to conserve the top soil. Provision has also recently been made for special advances for soil-erosion work to be made on the security of crops. In several areas the position is reported to be satisfactory but in others there is still much to be done. On the Plateau greater attention to soil erosion is necessary. The problem is largely one of finance in the European areas, as the settlers are now fully alive to the dangers to their lands from erosion. Special power plant for the construction of broad-base contour-ridges will be required if the work is to be hastened, and in some areas a greater measure of afforestation may have to be undertaken.

Bad erosion may be seen in parts of the North, Central and South Kavirondos, the West Suk, Elgazo, Kamasia, Samburu and Kamba Reserves. In the lower areas of Fort Hall and Embu, and in Kitui, there are some bad patches, whilst a certain degree of erosion is also to be seen in other areas, such as parts of Central Kavirondo and Kajiado. The Kamba and Kamasia Reserves probably present the most depressing pictures, and it is estimated that in the former over one-third of the total area (1,000,000 acres) of the Reserve is showing signs of erosion. Some very bad gully-erosion is to be seen in both Reserves.

The causes of the erosion in the Reserves are many and varied. Basic-

ally, they are due to the removal of the vegetation-cover and the exposure of the soil to the effects of the rain and the wind. This may have been brought about by the denudation of steep hill-sides of their forest-cover, by the practice of shifting cultivation on hill-sides without the use of anti-erosion measures, such as strip-cropping and contour-ridges. Grass fires, overgrazing, and the creation of cattle tracks by stock travelling to water and excessive stock populations, especially of goats, all play their part. Taking the Reserves in Kenya as a whole, cultivations are as responsible for erosion as is overstocking or overgrazing. In Masailand, which is purely pastoral, there is little serious erosion, but in the hilly reserves cultivations have given rise to much erosion directly, and also indirectly, through the reduction in the area and quality of the grazing. In these circumstances, overstocking has resulted and overgrazing has become serious. If the cultivations were reduced and rotational grazing practised the damage from overstocking would be lessened. The whole problem in these areas is to secure a satisfactory balance between agricultural and pastoral activities, and this is not likely to be achieved except through an intensification of agricultural methods or a reduction in stock numbers, or a combination of both.

In the Kamasia Reserve the damage is largely the result of the lack of adequate water-supplies for stock. This leads to the concentration of stock on the limited water-supplies, with soil damage caused by overtrampling and overgrazing. Stock-tracks between the water-courses also frequently develop into gullies. If the water-supplies could be augmented and the stock population spread throughout the whole Reserve with provision for rotational grazing, there would be less damage. There are areas, however, where the stock population is in excess of the grazing available, even if the water-supplies were augmented, and in these areas the reduction of stock numbers, and especially of the numbers of goats, will have to be contemplated if the countryside is to be saved. In the Kavirondos, the greater part of the erosion is caused by agricultural activities unaccompanied by the adoption of anti-erosion measures, and if soil deterioration is to be checked the introduction of animal husbandry into a system of mixed farming is desirable.

Reconditioning has been started in the Kamasia and Kamba Reserves. In the former 20,000 acres have already been dealt with, and it has been demonstrated that land retired from grazing can be covered in two or three years with a good cover of permanent grass capable of carrying limited numbers of stock. No goats have been permitted in the reconditioned areas and proposals for limiting the grazing of goats to defined areas in the Reserve are now under consideration. The construction of dams for the provision of additional water-supplies has already begun. In the Kavirondos, the Central Province, and the Kamba Reserve, the Department of Agriculture has laid down a number of demonstrations in the agricultural areas to illustrate the value of contour-planting of elephant grass, contour-ridging, stagger-trenching, &c. Reafforestation has also received attention but more work in this direction is necessary if steep lands and natural drainage channels are retired, as they should be, from agriculture or pasturage.

Sufficient has been indicated above to show that, whilst the problem is a serious one, it is dangerous to generalize as to the steps which should be taken to effect a cure. The basic cause or causes of the trouble must be determined in each area before remedies are decided upon. Anti-erosion works and reconditioning on a large scale will be needed, but these are unlikely to be of lasting effect unless efforts are made at the same time to improve the methods of agriculture and animal husbandry. The efforts made will require the co-operation of all branches of the Government service and the problem will have to be tackled on a wide front. Social and economic factors will have to be considered, as well as the technical issues which concern the Agricultural, Veterinary and Forest Departments. The Standing Board of Economic Development has recently undertaken to survey the position and has secured the services of an Agricultural Officer for this purpose. The Native Authority Ordinance has also recently been amended to provide that measures can be taken for dealing with soil erosion when necessary, and for the prevention of fires in the forest areas in Native Reserves. An attempt is also being made, through propaganda, to educate the people to the losses they may suffer if their lands are not conserved. Soil conservation has been, in fact, placed first on the list of the extension work of the Department of Agriculture in the Native Reserves, and useful assistance in propaganda work is being received from the Kenya Arbor Society.

Soil erosion in the Reserves has been gaining ground in recent years, but the position is one which can still be met if it is tackled on a wide front, and if the necessary measures are supported by determined efforts to improve the methods of agriculture and animal husbandry used by the peoples concerned. To provide for the one without the other would be futile, for within but a few years the position would become serious again, if the people were not to be condemned to economic and social stagnation.

Somaliland.—It has been evident of late that the pasturage for stock has been seriously deteriorating, and this has been confirmed by a series of aerial photographs. Uncontrolled grazing is leading steadily to destruction of vegetation and to increase of erosion. It has been demonstrated that a system of deferred grazing will enable the pasturage rapidly to recover, and the Government has enacted legislation which enables district officers to control grazing and to prohibit it in certain circumstances until after the grasses have flowered and seeded. This system, provided it is applied over wide areas, is likely to be effective, but the closure of areas to all grazing may have to be introduced in certain cases. The position in Somaliland is not at present as serious as in some other parts of Eastern Africa, and it is expected that the legislative measures now available will produce a great improvement within a few years.

Eastern Dependencies

Ceylon.—To any visitor to Ceylon during the monsoon rains, the waters in the rivers present ample evidence of the amount of soil that is being lost. From 1873 onwards attention has been constantly drawn to

the losses which were taking place. Little real interest was, however, taken in the question until about 1923, when a determined effort was made by the Department of Agriculture to arouse public and 'planting' interest. Clean weeding had been until then the accepted agricultural practice on both tea and rubber estates, but visitors to Java had been impressed by the steps which were being taken in that country to preserve its soils from erosion. The propaganda campaign met with a ready response from all classes of agriculturists. Contour-drains, silt-pits, contour-ridges, terracing and cover crops were all used with good effect. A Committee on Soil Erosion, whose report was issued early in 1931, reviewed the position fully, and stated that the successful propaganda work which had been done by the Department of Agriculture had been fruitful in stimulating agricultural interest in soil erosion, and in leading tea and rubber plantations to experiment in the use of cover crops, in new methods of opening land, and in modifying drainage systems. This Committee visited all parts of Ceylon and reported that a marked change in agricultural methods and outlook had taken place. It felt that the agriculturists of Ceylon were to be congratulated on the useful work of soil conservation which had been effected during the previous five years. It also commended the Department of Agriculture for the investigational and research work which it had undertaken, and suggested that the newly formed research organizations for the tea, rubber, and coconut industries should be asked to regard the problem of soil erosion as of the greatest importance, and to organize systematic investigational work in collaboration with the Department of Agriculture.

Crown Lands with a slope of 45 degrees or over can now be alienated only if the land is retained in forest and not opened for cultivation, or, if it is grass land, it is used solely for afforestation purposes. The Land Development Ordinance of 1935, further, makes it now possible for the Government to make regulations to provide for anti-soil erosion measures to be taken on any alienated Crown Lands.

During the years following 1931 the depression in the tea and rubber industries was responsible for a reduction of effort to cope with the soil-erosion problem, and propaganda on the part of the Government ceased. It is, however, pleasing to note that within the past year the interest of the Department of Agriculture has been revived, and it is gratifying to know that the Board of Agriculture recently passed unanimously a resolution asking for the appointment of a whole-time officer to carry out soil-erosion investigations and to organize propaganda. Propaganda designed to educate public opinion to a persistent demand for the control of soil erosion must be sustained to be effective, and if public opinion cannot be aroused to the seriousness of the situation the only course open to the Government is to consider legislative measures.

Malaya, like Ceylon, is a country with a high rainfall ranging between 75 and 150 in. per annum and in certain places even higher. A high mountain-ridge runs longitudinally down the country for two-thirds of its length from which a considerable number of rivers arise. The natural condition of the country is that it is clothed with high tropical rain-forest practically down to the sea coast; the removal of the forest-clothing

under these circumstances opens the way for erosion on a considerable scale unless steps are taken to prevent it.

The agricultural development of the country has been phenomenally rapid and is mainly due to the rise of the rubber industry, which now occupies over 3 million acres.

The position is further complicated by the occurrence of mining on a very large scale. The country possesses extensive tin deposits, for the most part in the form of alluvial deposits extending over large areas. These have been and are extensively worked, and this factor has contributed to erosion losses in an appreciable degree. In the early days of the development of European plantation industries agricultural methods favoured clean weeding, and in consequence very extensive soil losses occurred. In recent years, however, the dangers of the position have become increasingly realized and material improvement has resulted.

The first step consisted in the introduction on estates of silt-pitting, bunding, terracing and contour-draining. This was subsequently followed by the introduction of the planting of cover crops, and later by the development of the system of natural covers, locally known under the name of 'rubber forestry'.

On Asiatic-owned estates and on small holdings, the position was never so bad; clean weeding was never favoured to the same extent as on European properties.

The position in regard to shifting cultivation is more favourable, owing partly to the fact that the majority of the crops grown are permanent, whilst the system of land registration which is everywhere enforced in the Malay States enables the Governments to control the position to a considerable extent. The result is that shifting cultivation is mainly confined to small areas in mountainous regions which are worked by the primitive Sakei tribes, who are numerically small.

Some anxiety is at present felt, particularly in the State of Johore, about the rapid development of the cultivation of pineapples as a main crop on a large scale. In consequence, in all recent alienations of land for pineapple cultivation, considerable powers have been given to the Department of Agriculture to prescribe and enforce anti-erosion cultivation conditions. Similar apprehensions exist regarding the extension of tea and coffee cultivation in the Highland regions, and in this respect similar powers have been provided.

In 1933 the Federated Malay States Government adopted a revised form of the Silt Enactment of 1922, which affords wide powers to the Governments of the Federation to enforce anti-erosion measures. This, combined with the system of land tenure, under which all land in the Malay States vests in the Government and is alienated for cultivation subject to strict provisos regarding the crops to be cultivated, and the policy of forest reserves, which enables forest areas essential to protection to be retained, provides adequate machinery for the control of soil erosion due to agricultural occupation.

The mining policy is directed towards reducing soil losses. Working in closed mining circuits is now insisted on, the old fashioned form of mining hill-sides termed 'lampanning', which led to extensive losses

of soil and sub-soil, has been stopped, whilst the re-sliming of mined areas is being encouraged.

On the whole, it may be said that although the position is not free from anxiety, the Governments and the population are alive to the dangers, and adequate measures are being taken in most parts of the peninsula to deal with the question. An exception, however, exists in the island of Penang, where, owing to differences in the system of land-tenure, control over alienated lands is much less effective, and erosion is assuming considerable proportions in some localities.

Seychelles.—Erosion on the granitic islands, with high rainfall, is considerable; a scheme of reafforestation of the hill-tops of the island of Mahé has been sanctioned, and the necessary finance secured from the Colonial Development Fund.

West Indian Dependencies

Very little attention has been given to soil erosion in these dependencies, and generally speaking the loss of soil from this cause has not been as excessive as it has been elsewhere, mainly because clean weeding has never been adopted as an agricultural practice, and planting in holes has been general. Sugar-cane is planted in holes or furrows, and in the cultivation of many food crops the system of preparing holes and mounds is fairly common. In some of the mountainous islands with heavy rainfall, erosion has, however, been serious, and it has recently been recognized, in St. Vincent for example, that considerable erosion is taking place. In Jamaica, moreover, the position is serious in the Blue Mountain range, and has not received the attention it deserves. It is, indeed, fortunate that the calcareous soils of Jamaica do not erode readily as little or no attempt is made to check erosion, but the soils in the Blue Mountain range area derived from schists are easily erodible, whilst uncontrolled deforestation has been permitted to proceed too far in the island.

In St. Vincent, soil erosion can be really serious, and one or two small-holding settlement schemes have, in the Cumberland Valley of that island, been established on lands situate on hill slopes which should have been kept in permanent forest-cover. The condition of these smallholders, after some years on land of inferior quality subject to continued erosion, can well be imagined, and it is to be hoped that in all future settlement-schemes attention will be given to the selection of land of good average quality, and that no scheme be started until a satisfactory report on the land has been obtained from the Department of Agriculture. In St. Lucia, attention has recently been called by Mr. Wimbush, in his report on the forestry position in the Windward and Leeward Islands, to the unsuitability from the standpoint of erodibility of certain lands recently selected for development, and a reconsideration of the project has resulted in a revision of the proposals.

In Trinidad, the Imperial College of Tropical Agriculture is studying the amount of erosion on certain soil types in connexion with investigations relating to shifting cultivation.

More attention should, however, be directed to the question of soil erosion in all the wetter and more mountainous islands in the West

Indies, and all Colonial Agricultural Scholars should, whilst at the Imperial College of Tropical Agriculture, have their attention specially directed to the question.

Mediterranean Colonies

It is unnecessary to say much about the conditions in these Colonies. In *Malta*, terracing is general and soil erosion is not in excess of that which is normally experienced in the Mediterranean region. In *Cyprus*, serious erosion occurs after the heavy rain-storms which are experienced in the island. Invariably, the bunds of irrigation works are breached during these storms, and it is clear that when funds permit a wide system of loose-stone terracing should be undertaken to check the sweep of storm-waters towards the sea. The work is too large for individual effort, and could only be undertaken satisfactorily on an island-wide basis. It has been recognized, however, that the maintenance of a good forest-cover on the hill ranges of the island is essential, and if this policy is adopted not only should the underground water-supplies be assured, but some of the 'run-off' from the hill slopes be prevented.

In *Palestine* many areas have been eroded down to the bone. The central hill range has been reduced through the process of time to bare rocky slopes. From this range most of the soil has been washed away, and the lands of the plains are to no small degree derived from these washings from the hills. It is probable that the actual loss of soil has not been so great as it has been in many parts of the world, but during the rainy season the sea along the coast is often discoloured for lengthy periods by soil from the hills and plains of Palestine.

In the hills there are many examples of good terraces. Some of these date from the earliest times, whilst a few are of recent construction. When vineyards and fruit gardens are established, attempts are invariably made to form stone walls or terraces. Improvements could, however, be effected, and instances are frequently to be seen where stones have been carried quite considerable distances to form walled enclosures to the cultivations, instead of being utilized for the construction of rough stone ridges along the contours of the slope.

The loss that can be occasioned by soil erosion on the gentle slopes in the plains has also not been sufficiently realized, and the need for the establishment of ridge-terraces in certain of the Government experiment stations has become apparent.

Conclusion

An attempt has been made to survey the present position in regard to soil erosion in the Colonial Empire, to describe the measures which are being taken to check and control its effects, and to indicate where further efforts are required.

The most serious losses are taking place in East Africa, particularly in Kenya. Here the condition of some of the Native Reserves is becoming serious and deterioration is proceeding apace. It is the most important land problem which the country has to face, but if active steps are taken without delay the position can be greatly improved within a decade. The

actual causes of erosion are numerous and varied, and each drainage area of any country requires close examination before plans of reconditioning or control are decided upon. Untutored agricultural operations are responsible for erosion in many parts, whilst in others concentrations of stock numbers due to a shortage of grazing or inadequate water-supplies are the chief contributory causes. In yet others, stock numbers are in excess of the carrying capacity of the land and overgrazing takes place. Rotational or deferred grazing has been demonstrated to be effective as a cure in certain circumstances, and strip-cropping, contour-ridging, and mulching have proved their value in agricultural lands. There are many instances where deforestation has been excessive, and considerable areas of land may have to be retired from cultivation or grazing if the position is to be improved.

The problem is one which must be approached from various angles. Physical, biological, and social factors have to be considered, and there is no doubt that the fullest co-operation between the administrative and technical departments is essential if advances are to be made. Generalizations as to control measures must be avoided. Each area should be examined in detail and working plans evolved before any decision is taken as to how the problem should be tackled.

Vegetation-control is the most important method of controlling soil erosion, since it produces a cure by natural methods and is much less expensive than treatment by mechanical means. In cultivated lands on hilly slopes, however, the use of contour-ridges, terraces, hedges and drains is necessary when strip-cropping cannot be adopted, if the fertile top soil is to be saved.

The use of control measures, without an improvement in the systems of agriculture and animal husbandry, is likely to be unsatisfactory. Such a policy meets only the circumstances of the present and does not provide for the future. Expenditure on anti-erosion measures should at least be matched with expenditure of a similar magnitude for agricultural education, demonstration and propaganda, if the future is to be secured.

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MILKING EXPERIMENTS WITH SHEEP IN CYPRUS

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WITH PLATE 9

Introduction.—Sheep are kept in Cyprus primarily for milk, the production of lamb, mutton, and wool being of secondary importance. Most of the milk is made into cheese, sour milk (*yaourt*), and other milk products which constitute the main sources of protein supply for the rural population. The local breed is the coarse-woolled, fat-tailed type, which is also found elsewhere in the Near East, principally in Palestine, Syria, and Turkey (Plate 9, Fig. 1). The Palestinian breed has been described by Hirsh [1], and is probably the one most nearly akin to the Cyprus sheep. The main characteristic of these sheep is their extreme hardiness and ability to live on the minimum rough grazing which, during the hot dry summer, consists only of weeds, stubbles, and dry grass. Their fat tail is a reserve which can be drawn upon during periods of scarcity. Lambing starts in October or November when winter begins, and continues till February, the milking period lasting up to May or June.

The flock at the Government Stock Farm was founded in 1904, and for many years the object was to improve the quality of the wool. To this end a few South African Merino sheep were imported in 1928 and crossed with the local breed.

The cross-bred sheep had a much better fleece but only a slight 'fat tail'. These first-cross sheep were not popular, since it was believed that they did not milk so well as the local sheep. It was with a view to ascertaining their milking qualities in comparison with the local sheep that the first of the two experiments described here was undertaken. Before 1935 no milk-recording of sheep had been done, and the carrying out of the first experiment was therefore no light undertaking among people who had no previous experience of experimental work.

The second experiment was planned mainly as a result of the report of the Agricultural Adviser to the Secretary of State for the Colonies, on his visit to Palestine [2], in order to discover what effect the feeding of a supplementary ration might have on the milk-yield of ewes.

The available information concerning the yield and composition of ewes' milk was summarized by Godden and Puddy in a recent article [3]. The information regarding the yield of certain continental breeds of milch sheep shows that the yield varies from 20 to 644 kg. for periods of 100–179 days, respectively, but the East Friesian breed, to which the highest figures refer, are exceptionally good milkers, and the normal yield of milch ewes in southern Europe and the Near East is more probably around 50–100 kg. in 4 or 5 months.

In southern France the yield is said to be from 70 to 130 kg. (Larzac breed) [4], and in Palestine Hirsh [1] gives the average yield for the country as 40 kg., though under specially favourable conditions average

yields of 64 kg. have been obtained. Similar figures are quoted by Spöttel [5] for the Kivirdjik sheep in western Anatolia, the stated averages being 30–60 kg., and 25 kg. for Karaman sheep.

In Cyprus the yields vary from 25 to 75 kg., the average probably being about 40 to 45 kg. At the Government Stock Farm the average yield of 22 native ewes was 52 kg. in 1935, and that of 26 native ewes 75 kg. in 1936. Elsewhere in Cyprus accurate recording of a flock of over 400 ewes in 1935–6 gave an average of 67 kg., with a range of 10–160 kg. [6]. This figure, however, represents a standardized milk-yield based on a suckling period of 30 days, for all ewes.

The 1935 Experiment

To compare the milking abilities of the local with the cross-bred Merino-Cyprus sheep, 16 ewes of each breed were selected and divided into four groups of 8 ewes, Groups 1 and 3 consisting of native ewes, and Groups 2 and 4 of cross-bred ewes. In the first two groups the lambs were disposed of when approximately 4 weeks old, and the ewes were milked twice daily until they began to go dry. In the 3rd and 4th groups the ewes suckled their lambs for about 2 months, and the lambs were then weaned gradually by separating them from their mothers at nightfall and milking the ewes in the morning. The first method of treatment is that most favoured among flock-owners, who wish to obtain as much milk as possible in the early lambing months, when the price of milk is high. About 70 per cent. of lambs is sold at 2–4 weeks, and it is mostly the later-born lambs that are reared on their mothers.

Part I.—The experiment was begun on Jan. 5, 1935, with Groups 1 and 2. The interval between lambing and first milking averaged 32 days for the 16 ewes. Two ewes, however (one from each group) had to be eliminated within 3 weeks for different reasons. The remaining 14 ewes were milked for 96 days, when 4 more were eliminated, of which 3 were dry. The remaining 10 ewes (5 in each group) were milked for a further period of 42 days until May 23, when all but a few were dry; for the last 3 weeks of this period they were milked only once daily. For the full period of 138 days the yields of only 5 ewes in each group are given in Table 1, but for the first 96 days the average of 7 ewes in each group is given. Of the 14 ewes only one had twins; 12 lambs were sold and three died, including one twin.

Part II.—In Groups 3 and 4, the 16 ewes selected had all lambed single lambs which, when milking began, were approximately 6–8 weeks old. Milking was started on Feb. 1 and for 70 days (i.e. until April 11) was done once a day, the lambs suckling during the daytime. On April 12 the lambs were sold or weaned, and 4 ewes (2 from each group) were eliminated on account of very low yield. From April 12 to May 23 the remainder were milked twice daily (42 days) until they began to dry off, and once a day thereafter. Two ewes went dry before May 23, but for the full period of 112 days the yields of 6 ewes in each group have been taken.

Milking and Feeding.—Milking was done in the early morning, and, in the case of Groups 1 and 2, again in the evening just before sunset. As

the days lengthened, so did the period between morning and evening milkings. This, however, is common practice in Cyprus, as it enables the flock to get as much grazing as possible during the day. The ewes were milked on a raised wooden stand with detachable sloping platforms by which to enter and leave. A box for food was attached to the front. The ewes were milked from behind into a container, and the milk was then weighed and recorded. Figs. 2 and 3 illustrate these stands and the method of milking. The ewes soon became accustomed to this stand and ran up the platform of their own accord. Each ewe was allowed a small quantity of food (bran and oats) while being milked, but the average consumption was only about ¼ lb. per head per milking. The object of feeding this ration was to keep the ewes occupied during milking, rather than to supply a supplementary ration for milk-production. All groups were treated alike as regards hours of grazing and routine management.

Milk-Yields.—The average yields per ewe for the different periods of the experiment are given in Table 1, and for the individual ewes in Table 2.

TABLE 1. *Average Yields of Ewes*

Groups	*No. of ewes per group*	*No. of days milked*	*Average yield per ewe in kg.*		
			Native	*Cross-bred*	*Difference*
1 and 2	7	96	58·5	48·5	10·0
1 and 2	5	138	77·4	60·6	16·8
1 and 2	7	138	71·0	56·2	14·8
3 and 4	8	70	33·6	30·9	2·7
3 and 4	6	112	49·0	44·7	4·3
3 and 4	8	112	44·9	41·3	3·6

Groups 1 and 2.—Group 1 (native ewes) gave consistently higher average yields throughout the experiment. The cross-bred ewes (Group 2) reached their maximum yield after 7–8 weeks' milking, and then began to decrease, whereas the native ewes reached their maximum in 9–10 weeks, and did not decrease so rapidly. Thus the difference in yield per group was greater after the second month of the experiment. The maximum daily yields were:

Group 1: 0·7 kg. per ewe in the 13th week after lambing.
Group 2: 0·6 kg. per ewe in the 11th week after lambing.

The yields in the first 96 days of the experiment, when the maximum number of ewes were included in each group, show that the total increase of Group 1 over Group 2 was 10 kg. per ewe, or 20 per cent. This is equivalent to an increase of 104 gm. per ewe per day. When the yields of the 5 ewes in each group which were milked for 138 days are compared, the increase of Group 1 over Group 2 is 16·8 kg. per ewe, or 27 per cent., equivalent to 122 gm. per ewe per day. For all ewes, for the full period of the experiment, the increase was 14·8 kg. per ewe or 26 per cent., equivalent to 107 gm. per day.

These increases can also be represented in terms of the increased receipts that would be obtained when the price of milk is 2*d*. per kg., which is the average price in January to April. The differences per group

of 104–22 gm. per ewe per day are equal to a gain of from 6*d.* to 7*d.* per ewe per month, or 2*s.* 6*d.* to 3*s.* per ewe in a lactation-period of 5 months.

Groups 3 and 4.—The difference between these two groups was very much less than in Groups 1 and 2; and both gave almost equal yields per ewe during the weaning period (70 days), when they were only milked once a day. The difference in favour of the native ewes (Group 3) was only 2·7 kg. per ewe or 39 gm. per day, which is an increase of 9 per cent.

TABLE 2. *Individual Yields of Ewes in 1935 Experiment*

Group 1 (Native ewes)			*Group 2 (Cross-bred ewes)*		
No. of ewe	*Yield (kg.)*	*Days*	*No. of ewe*	*Yield (kg.)*	*Days*
21	73·9	138	22	60·1	138
23	91·8	138	24	65·7	138
25	82·1	138	26	56·2	96
27	61·5	96	30	44·6	138
29	75·4	138	32	34·0	96
31	63·5	138	34	76·5	138
35	48·6	110	36	58·2	138
Average 71·0 kg.			Average 56·4 kg.		
Group 3 (Native ewes)			*Group 4 (Cross-bred ewes)*		
No. of ewe	*Yield (kg.)*	*Days*	*No. of ewe*	*Yield (kg.)*	*Days*
37	32·1	70	38	35·4	70
39	53·8	112	40	45·2	112
41	33·4	70	42	42·9	112
43	53·2	112	44	38·7	98
45	46·0	98	46	58·1	112
47	52·0	112	48	43·8	112
49	43·5	112	50	39·8	112
51	45·1	112	52	26·2	70
Average 44·9 kg.			Average 41·26 kg.		

For the full period of 112 days the difference increased to 4·3 kg. per ewe for the 6 ewes which were milked for this period, or 3·6 kg. when all ewes are taken into account. These increases are equivalent to approx. 39 gm. per ewe per day, or in terms of increased receipts, to 2·3*d.* per ewe per month, or roughly 1*s.* in a lactation-period of 5 months. Although these figures represent increases of only 9 to 10 per cent. of Group 3 over Group 4, they do show a slight but definite financial gain.

Average Daily Yields.—Table 3 gives the average daily yields of the ewes in each group for different periods of the experiment, and shows that there is not a great difference between ewes of the same breed, whether milked twice a day when the lambs were sold, or once a day while still suckling their lambs.

Results.—(1) The native sheep were better milkers than the cross-bred sheep. This difference is emphasized in the commoner local method of management, viz. the early disposal of the lambs, when the yield of native ewes was from 20 to 27 per cent. higher.

(2) The average yields per day did not differ as much as would be

expected between ewes of the same breed when milked once or twice daily. The increase when milked twice daily was only 64–129 gm. over the yield of ewes suckling their lambs for 10–12 hours a day.

TABLE 3. *Average Daily Yields of Ewes*

Group	*Breed and management of ewes*	*No. of days milked*	*Average yield per day (gm.)*
1	7 native ewes without lambs	96	609
3	8 native ewes suckling lambs	70	480
2	7 cross-bred ewes without lambs	96	505
4	8 cross-bred ewes suckling lambs	70	441

(3) The individual yields of 7 native ewes milked for 3–4½ months (Group 1) varied from 49 to 92 kg., and for 8 native ewes, suckling lambs and milked for 2½ up to 3½ months, they varied from 32 to 54 kg. (Group 3). Cross-bred ewes for similar periods and conditions gave from 34 to 76 kg. (Group 2) and from 26 to 58 kg. (Group 4).

The 1936 Experiment

This experiment was planned to ascertain the effect on the milk-yield of feeding a supplementary ration of 1 lb. (½ kg. approx.) of concentrates per head per day in addition to the ordinary 9–10 hours grazing. The local practice of most shepherds is to allow their ewes to graze all day on the fallow and grazing lands of the village, and only rarely do they feed any extra chaff or other food. The quantity and quality of grazing available depends on the rainfall and weather; if there is early rainfall in October and November the grazing is good, but if the rains are late or do not continue into February and March, the grazing may be seriously affected. (The average rainfall at the Government Stock Farm for 32 years is 13·78 in.) In October 1935 there was a good rainfall, and grazing was plentiful from November 1935 to January 1936; thereafter there was very little rain and the grazing dried up rapidly. On the Government Stock Farm, however, there is usually much more grazing than outside, owing to the small number of stock carried per acre, and for this reason the flock is usually on a higher plane of nutrition than neighbouring flocks whose grazing is always restricted. Local shepherds always consider that the conditions under which the Government flock is kept are far better than anywhere in the district and hence, although they might consider extra feeding would be beneficial to their own flocks, they would seldom agree that it was either necessary or economic on the Government Stock Farm. Nevertheless the experiment was carried out to see whether such additional feeding in a year of 'average' rainfall would both affect the milk-yield and prove an economic proposition under normal conditions.

Thirty ewes were selected comprising 20 fat-tailed and 10 cross-bred ewes, the latter being included to increase the number of experimental animals. The ewes were divided into two groups of 15 ewes each (10

native and 5 cross-bred), taking into consideration their previous years' performance, and date of lambing.

Group 1 was the control group and Group 2 the experimental group. The hours of grazing were alike for both groups and all other treatments were similar. Milking was begun about 7 to 8 weeks after lambing, and for the first 15 days was done once a day (in the early morning), the lambs being allowed to suckle during the day. Thereafter the lambs were weaned, and milking was done regularly twice daily. Since the size of the flock made it impossible to have sufficient ewes lambing within a few days of each other, it was necessary to arrange the dates on which milking was begun according to the dates of lambing. In consequence milking was begun at intervals as follows: Jan. 2 (4 ewes), Jan. 17 (8 ewes), Feb. 1 (1 ewe), and Feb. 16 (17 ewes), i.e. milking was begun with each batch of ewes as their lambs completed the appropriate period of unrestricted suckling. This period averaged 52 days for Group 1 and 53 days for Group 2.

The cross-bred ewes lambed first, and 4 of them went dry after only 60 days' milking, 3 more dried off after 75 days, and one died after 75 days; 2 native ewes went dry early, so that only 20 ewes were milked for the full period of the experiment, 105 days.

The experiment ended on May 30, when yields were beginning to fall and more ewes to go dry. Thus the 15 ewes in each group could be compared for only 60 days' milking; and for the full period of 105 days the yields of 9 native ewes in each group are compared in addition to the average yield for all ewes. These are all given in Table 4.

TABLE 4. *Yields of Ewes*

No. of ewes in each group	*No. of days milked*	*Average yield per ewe in kg.*		
		Group 1	*Group 2*	*Difference*
15	60	40·1	43·7	3·6
9 (native)	105	68·0	72·5	4·5
15	105	57·0	62·3	5·3

Methods of Milking and Feeding.—The method of milking was similar to that used in 1935, except that the milking-stands were improved and only Group 2 received any food at milking time. The method of management was to separate the milkers from the rest of the flock before the evening milking, and to feed and milk them in two or three batches. Each batch was separated and the ewes allowed to enter the stands of their own accord, which they soon learnt to do; the food was weighed out by means of a tin holding the exact quantity; while the ewes were feeding they were milked, and then allowed to finish their food before another batch was brought in. Occasionally a ewe would not clear up all its food, but generally they relished it and no difficulty was experienced in accustoming them to use the stands or to feed. The ration consisted of: 2 parts crushed oats, 2 parts bran, and 1 part gram (local name 'Favetta'); and had the following analysis (per cent.): water 12·40, protein 14·12,

fat 3·34, carbohydrates 55.17, fibre 10·02, ash 4·95. The cost of this ration was calculated from current prices to be 0·46*d.* per lb.

Milk-Yields.—The average yields of the ewes for different periods of the experiment are given in Table 4, and those for the individual ewes in Table 5. There is only a very slight increase in yield of Group 2, the 'concentrate' group, over Group 1, varying from 3·6 kg. per ewe in 60 days, to 5·3 kg. in 105 days. These increases are equivalent to from 50 to 60 gm. per ewe per day. When the 9 native ewes in each group which were milked for 105 days are considered, the increase is rather less, being 4·5 kg. per ewe in 105 days or 43 gm. per ewe per day.

TABLE 5. *Individual Yields of Ewes (in kg.), 1936*

No. and breed of ewe	Group 1 *Yield*	Group 1 *Days*	*No. and breed of ewe*	Group 2 *Yield*	Group 2 *Days*
34 CB	35·7	75	22 CB	62·3	105
48 CB	34·8	75	46 CB	63·4	75*
88 CB	28·5	60	50 CB	32·7	60
108 CB	38·1	75	90 CB	26·6	60
118 CB	75·9	105	106 CB	44·7	75
39 N	92·7	105	45 N	54·0	75
25 N	85·3	105	21 N	74·1	105
54 N	29·4	60	53 N	68·0	105
49 N	70·9	105	160 N	61·3	105
51 N	58·4	105	23 N	100·1	105
58 N	63·4	105	89 N	91·4	105
63 N	40·0	105	43 N	73·9	105
47 N	76·0	105	31 N	53·4	105
178 N	53·7	105	67 N	82·0	105
29 N	71·1	105	41 N	48·0	105
Average 57·0 kg.			Average 62·3 kg.		

* Died after 75 days.

The maximum daily yields per ewe were: Group 1, 0·84 kg., and Group 2, 0·88 kg. per day.

The average daily yields of the ewes in each group for different periods of the experiment are given in Table 6.

TABLE 6. *Average Daily Yields of Ewes*

Group	*No. of ewes*	*No. of days milked*	*Average daily yield (gm.)*
1	15 ewes	60	670
2	15 ewes	60	730
1	9 native ewes	105	645
2	9 native ewes	105	691

These figures are higher than those obtained in 1935, by approximately 150 gm. per ewe.

Economics of the Experiment.—When the increase in yield of Group 2 over Group 1 is considered in terms of the increased receipts for milk

compared with the expenditure incurred in feeding the ewes, the following figures are obtained:

For 60 days' milking (average 15 ewes):

	s.	d.
Cost of 60 lb. of concentrates at 0·46*d.* per lb.	2	$3\frac{1}{2}$
Value of 3·6 kg. of milk at 2*d.* per kg.		$7\frac{1}{2}$
Net loss per ewe	1	8

Or, for 105 days (average of 9 ewes):

	s.	d.
Cost of 105 lb. concentrates at 0·46*d.* per lb.	4	0
Value of 4·5 kg. milk at 2*d.* per kg.		9
Net loss per ewe	3	3

Thus there is a very decided loss incurred in feeding this supplementary ration. The slight increase obtained is clearly not worth the expense entailed.

It was, unfortunately, impossible to ascertain whether the ewes increased in live weight during the experiment, for it seems probable that, as the food was not used by the ewes for increasing milk-yield, it was being converted into fat. Against this suggestion there is the possibility that these ewes did not graze so intensively and continuously as the others, since they knew that there was extra food when they returned to the sheep-yard. This point was remarked upon by the shepherd in charge of the flock, who said that these ewes appeared anxious to return about one hour earlier than usual and did not graze well in the later afternoon.

Results.—(1) The experiment indicates that the effect of feeding 1 lb. ($\frac{1}{2}$ kg.) of concentrates per head per day was extremely slight. The increase was only 60 gm. per ewe at first, falling to under 50 gm. when only native ewes were included.

(2) The increased yield obtained is unremunerative under the conditions obtaining on the Government Stock Farm in an average year. It represents $4\frac{1}{2}$ to 5 kg. per ewe in 105 days which is worth roughly not more than 1*s.*, whereas the value of the food is approximately 4*s.*, which is equivalent to a loss of at least 3*s.*

(3) The cross-bred ewes were again found to be neither such heavy nor such persistent milkers as the native ewes, the average of 10 cross-bred ewes being 44 kg. for an average of 76 days' milking, and of the 20 native ewes 67 kg. in 101 days.

Individual Milk Yields

In Table 7, the performance of a few average individual fat-tailed ewes for the years 1935 and 1936 are set out in order to give some idea of the capabilities of this breed. In 1936 butter-fat tests were made once or twice every month, both for the flock and for several individual ewes. The average butter-fat percentage for morning milk of all ewes was 7·80, and for evening milk 8·95, whilst the maximum and minimum daily tests of individual ewes were 4·4 and 9·8.

TABLE 7. *Individual Yields of Nine Native Ewes 1935–6 (in kg.)*

No. of ewe	*Yield 1935*	*Days milked*	*Average yield per day*	*Yield 1936*	*Days milked*	*Average yield per day*	*Butter-fat %, 1936*
23	100	162	0·62	125	147	0·85	8·3
25	82	138	0·60	115	164	0·70	7·3
39	54	112	0·48	129	182	0·71	8·0
67	37	84	0·44	90	133	0·69	8·5
21	79	162	0·49	91	152	0·60	8·2
58	56	108	0·52	69	126	0·54	8·4
31	64	138	0·46	58	126	0·46	8·2
41	44	112	0·40	51	119	0·43	8·2
63	27	84	0·32	41	105	0·40	7·8

Flock Average: 1935 (22 ewes) 52·2 kg. in 111 days = 0·47 kg. per day.
1936 (26 ewes) 74·8 kg. in 130 days = 0·58 kg. per day.

The yields of 9 ewes are given in the Table of which 3 were above average production, 4 are approximately average milkers, and 2 are below average. The flock averages for the 2 years are given below the Table. Ewe No. 23 is the best ewe in the flock, and she has given the highest yield per day in both years.

Summary

1. Two experiments on the milking capacities of native and cross-bred Merino-Cyprus sheep are described.

2. The Cyprus fat-tailed sheep are better milkers than the cross-bred Merino-Cyprus sheep.

3. Milk-yield was not significantly increased by feeding 'concentrates' as a supplement.

4. The average yield of the Cyprus fat-tailed sheep in the flock at the Government Stock Farm (during the 2 years) increased from 52 to 75 kg., which compares with about 60 kg. for a well-managed flock kept under favourable conditions in Cyprus.

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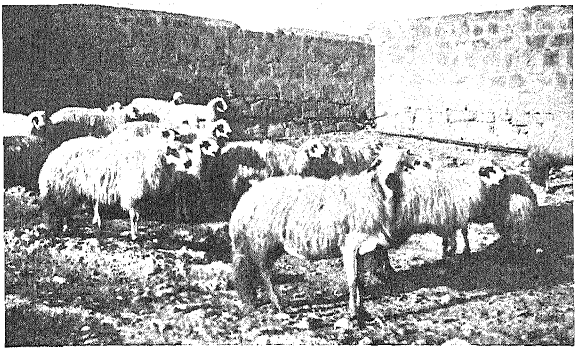

FIG. 1. Cyprus fat-tailed ewes

FIG. 2. Milking ewes, in stands

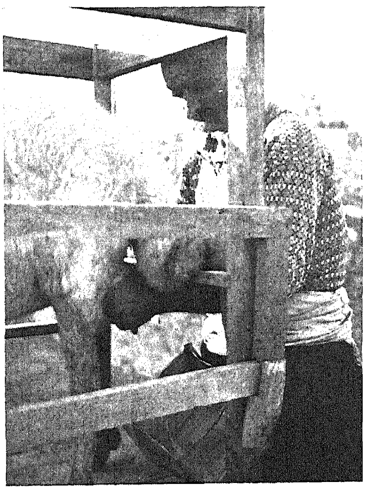

FIG. 3. Milking—note tail resting on bar

A STUDY OF THE GROUP-STRUCTURE OF MERINO FLEECES

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WITH PLATE 10

Introduction.—The fleece of the merino is composed of staples, often varying in size with different individuals and on different parts of the body of the same individual. A close examination of these staples will show that they can repeatedly be subdivided into smaller and smaller groups until small strands or fibre-bundles are ultimately obtained. The different groups are probably held together in the fleece by means of fibres from one group getting mixed up with the fibres from another group during growth; probably also by a certain amount of felting at the tips, by the crimpy structure of the fibres, and the accumulated fat and suint produced by the skin. This study was undertaken to obtain further information concerning the characteristics of these strands.

Material used.—The material used was obtained from nine four- to six-tooth wethers, bred and reared under exactly the same veld conditions in the north-eastern districts of the Cape Province. The sheep all carried ten months' growth of wool.

All samples were cut close to the skin with curved scissors. The belly samples were taken a few inches in front of the urinal opening; all the other samples were taken from the left side. The shoulder samples were taken on the middle of the shoulder-blade, those from the side on the last rib, and the britch samples close to the thurl. The line of sampling was parallel to the top line of the animal.

In order to obtain wool with fibre-groups fairly clearly defined, sheep carrying wool inclined to be ropy or watery were selected. In fact, most of the belly samples were watery. Some of the samples taken from the other parts of the body were ropy, and others were of fairly good staple-formation.

Method of study.—From each sample (2×2 cm.) a number of strands or fibre-bundles were carefully isolated, special care being taken not to break or to remove any fibres belonging to a strand. The unstretched length of each strand was measured in millimetres and the total number of crimps along the whole length of the strand was counted. Individual strands were then dipped in ether to remove most of the ether-soluble substances, as this procedure facilitates the removal of individual fibres from the strands. Each of the fibres was then separated from the strand, care being taken not to break or stretch the fibres, the straight length measured, and the number of crimps counted. It was found to be very difficult to obtain representative results by removing only a portion of the fibres from the strand. The thicker fibres are usually more prominent, and as they are also more apt to detach themselves from the strand, they are inevitably selected. Roberts [1] has shown that the first fibres selected at random from a sample are actually the coarsest.

Of each strand analysed we therefore had the number of fibres composing it, the number of crimps, the average number of crimps per fibre, the staple or crimped length, and the average straight length of the fibres. For the samples of four sheep the average diameter of fibres of each of the strands was also determined.

After counting the crimps and measuring the straight length of individual fibres composing a strand, they were graded into length-classes, the class units differing by 5 mm. each. The average diameter of each of these length-classes was determined for all the strands selected from the samples of five sheep. For the rest, the average number of crimps per fibre in each of the length-classes was determined.

The number of crimps per fibre was found by laying out the separate fibres on a black plush cloth and counting the crimps by the aid of binoculars with a $\times 25$ enlargement. The straight length of each fibre was obtained by holding both ends of the fibre by means of forceps, stretching the fibres until the crimps were very nearly flattened, and then reading off the length along a millimetre-scale. One millimetre was added to the length of each fibre to correct for the portions held in the jaws of the forceps. Burns [2], Duerden and Bosman [3, 4], Baumgart [5], Spöttel [6], Duerden with Murray and Botha [7], and Roberts [1], have all used this method of length-determination.

In this study the numbers of fibres measured for length varied from 200 to 600 for each sample, according to the number of strands studied and the variation in the number of fibres per strand. According to Frölich, Tänzer, and Spöttel [8], Scholz considers the average of 15 length-measurements and Schadow 100 length-measurements to be representative for a sample; Burns [2] regards 50 as representative, whilst Duerden and Bosman [3] measured 100 fibres. Spöttell [6] states that at least 300 fibres must be taken to obtain a representative average length-measurement.

To obtain the average diameter of samples 8 to 10 sub-samples were taken from different parts of the sample. These were washed in ether, allowed to dry, then tightly rolled in paper, and very short portions were cut from the lower, middle, and top parts. The cuttings were brought on a glass slide, thoroughly mixed, and mounted in glycerin-gelatin. Five hundred diameter measurements were then taken under a Leitz microscope with $\times 700$ enlargement and a micrometer value of 2·093 microns.

When, in determining the average thickness of length-classes or small strands, the number of fibres was too small for this method to be applicable, all the fibres were cut up finely in a dish, thoroughly mixed, and only 200 measurements were made. This number proved to be ample for length-classes as a close correlation exists between length and diameter in a staple; if there is only a small variation in length there is only a small variation in diameter. In a length-class the difference between the average diameters obtained by two sets of measurements was only $0{\cdot}0628 \pm 0{\cdot}3767$ microns. With strands fairly accurate results were also obtained, the difference between the diameters obtained from two sets of measurements of the same strand amounting to $0{\cdot}2093 \pm 0{\cdot}3520$ micron.

The strands or fibre-bundles.—Frölich, Tänzer, and Spöttel [8] point out that so long ago as the middle of the nineteenth century several research workers observed the tendency towards grouping of fibres in the skin of mammals, and this observation was subsequently confirmed by other scientists, e.g. Tänzer and Spöttel [8], Zorn [8], Teodoreanu [9], and Sturm [10].

Frölich, Tänzer, and Spöttel consider this group arrangement of the fibres in the skin to be of the utmost importance to the structure of the fleece. The fibres of a group are inclined to adhere together even when they protrude from the skin. These fibre-groups may then stand alone or form strands with neighbouring groups. These strands may again join with others to form greater units in the form of small staples, and these again may unite to form still larger staples, and so on. When studying these strands it is therefore difficult to know whether one has to do with a bundle of fibres arising from one group of follicles, or with a collection of two or more bundles emerging from more than one group of follicles. In wool that is inclined to be stringy the strands are usually small and more easily isolated, and there is probably a greater tendency for a strand to consist of a bundle of fibres produced from one or, at most, from a few follicle-groups. Stringy or watery wool therefore represents the best material for such a study.

Size of strands.—Table 1 gives the average number of fibres per strand on different parts of the body of merino sheep. The figures are based on analyses of 123 strands taken from the different regions of the body of nine merino sheep. The total number of fibres studied was 15,074.

TABLE 1. *Average Number of Fibres per Strand*

Sheep No.	*Belly*	*Shoulder*	*Side*	*Britch*
1	47 (6)*	40 (5)	52 (5)	82 (3)
2	31 (8)	166 (2)	..	177 (2)
3	36 (8)	51 (4)	48 (4)	55 (4)
4	56 (5)	65 (2)	90 (3)	310 (2)
5	86 (4)	165 (2)	190 (2)	547 (5)
6	65 (4)	145 (2)	154 (2)	342 (2)
7	124 (3)	686 (3)	..	602 (3)
8	34 (8)	217 (3)	66 (4)	125 (3)
9	55 (5)	313 (2)	..	255 (3)

* Figures in brackets denote number of strands studied.

Table 1 shows that on the average a much greater number of fibres composes a strand in a fleece than composes a group in the skin, if the figures given by Frölich, Tänzer, and Spöttel, and by Teodoreanu are considered representative. According to Teodoreanu [9] a group in the skin consists of an average of approximately 18 fibres on the shoulder and 20 on the belly, whereas the average number of fibres composing a strand was found by us to be about 200 and 60 respectively. The size of the strands on the side corresponds more or less with that of the shoulder, but on the britch the strands are considerably larger than on any other part of the body, averaging about 280 fibres per strand. The

belly-wool seems to have the smallest strands, the britch the largest, with the side and shoulder wool taking an intermediate position.

Since the strands in the fleece consist of a considerably greater number of fibres than given for the groups in the skin, and the strand size is greater on the shoulder than on the belly, whereas the groups in the skin tend to be greater on the belly than on the shoulder, it appears that the single strands do not always correspond with single groups in the skin. They are more likely produced by a grouping of fibres growing from one or more neighbouring follicle-groups in the skin. Unfortunately, sheep could not be obtained for making comparative skin sections.

In the britch samples and some of those from other regions of the body, it was difficult to isolate the strands, because they were not clearly defined. It is thus possible that some of the strands studied, especially those which were composed of a large number of fibres, were actually a collection of two or more strands or portions of strands.

It was found that the strands from the same staple may vary considerably in the number of fibres composing the different strands. Both Tables 1 and 2 show, however, that the strand-size may be an individual characteristic for sheep, as the average number of fibres per strand differs considerably for different individuals, and these differences hold good to some extent for the different parts of the body.

In Table 2 the analytical data of individual strands taken from samples of three sheep are given for illustration.

TABLE 2. *Analysis of Strands*

1	2	3	4	5	6	7	8	9
No.	*Place*	*Fibres per strand No.*	*Staple-length per strand (mm.)*	*Av. fibre-length per strand (mm.)*	*Crimps per strand No.*	*Crimps per fibre in strand (av. no.)*	*Av. fibre-diameter of strands (microns)*	*Crimp per cent.*
1	Belly	27	62	100·6	36	37·5	..	38
		29	62	103·7	36	36·7	..	40
		42	58	102·3	36	41·9	..	43
		52	66	107·6	36	42·6	..	39
		63	60	106·8	40	42·2	..	44
		68	64	105·2	37	40·3	..	39
1	Shoulder	15	60	77·3	35	32·8	..	22
		27	60	83·1	35	33·0	..	28
		31	60	84·6	35	34·6	..	29
		60	62	92·1	35	35·7	..	33
		67	62	97·0	35	36·6	..	36
1	Side	37	54	84·3	37	33·8	..	36
		48	56	89·0	37	39·4	..	37
		55	57	89·8	40	39·2	..	36
		57	57	90·2	37	40·0	..	37
		62	55	89·7	37	39·1	..	39
1	Britch	71	50	70·8	24	25·1	..	29
		87	52	70·1	25	24·8	..	26
		88	53	72·1	26	25·4	..	26

TABLE 2. *Analysis of Strands* (*cont.*)

1	2	3	4	5	6	7	8	9
No.	*Place*	*Fibres per strand No.*	*Staple-length per strand (mm.)*	*Av. fibre-length per strand (mm.)*	*Crimps per strand No.*	*Crimps per fibre in strand (av. no.)*	*Av. fibre-diameter of strands (microns)*	*Crimp per cent.*
6	Belly	25	45	84·0	32	36·0	17·0	46
		60	58	90·0	40	41·0	18·1	36
		70	63	88·0	40	42·3	18·3	28
		105	60	96·4	48	48·4	19·6	38
6	Shoulder	120	71	91·9	50	46·2	..	23
		170	71	95·2	53	49·5	..	24
6	Side	132	70	94·3	49	46·2	16·6	26
		177	70	93·6	49	50·4	17·6	25
6	Britch	285	68	79·5	38	37·0	19·0	14
		400	70	80·1	40	38·6	19·0	13
8	Belly	26	36	79·6	31	34·1	23·1	55
		31	40	87·7	34	33·9	22·7	54
		32	40	80·0	34	34·8	23·0	50
		32	35	72·2	27	31·6	22·7	51
		34	40	84·3	34	33·5	22·0	52
		35	35	84·7	36	32·9	22·9	59
		40	38	84·7	28	34·7	24·5	55
		42	40	82·0	31	35·2	24·8	51
8	Shoulder	172	55	77·9	41	38·6	20·8	29
		210	55	84·4	43	41·1	21·7	35
		260	58	80·6	44	42·2	23·0	28
8	Side	50	46	75·1	39	37·0	21·5	39
		59	44	75·8	38	39·1	21·7	42
		65	44	75·6	38	39·6	22·3	42
		92	44	74·7	38	39·3	22·9	41
8	Britch	100	54	70·8	33	28·0	21·4	24
		137	51	70·6	29	29·1	21·3	28
		139	52	70·1	33	28·4	19·0	26

Length of strands.—The fibres composing a strand may vary considerably in length (straight). Even in strands where the tips are cut, or where the tips are naturally very even [Plate 10, Fig. 1 (*b*)] this wide variation is still found. The longest fibres in a strand are usually one and a half times longer than the shortest fibres.

Distribution-curves of the length of fibres composing individual strands isolated from the same sample show that the mode of one curve may fall in a place totally different from that of another curve. Also the average straight fibre-length of the different strands constituting a sample may vary considerably (Table 2). In sheep No. 1 the average fibre-length of one strand in the sample was 97·0 mm. and another only 77·3 mm., a difference of nearly 2 cm. This shows that

sampling has to be done very carefully when the average fibre-length of a sample or even that of a single staple is to be determined.

Fibre-diameter of strands.—A considerable variation was found also in the diameter of the fibres composing a strand. As a close correlation exists between the length of fibre and its diameter [4, 5, 11], the longer fibres must also be the coarser ones. This shows that there must be considerable variation in the rate of cell-production, even in neighbouring follicles. A variation was also apparent in the average fibre-diameter of the strands composing a sample. Differences in the average diameter of strands as large as 3·7 microns were found in a belly sample, 2·4 microns in a britch sample, 2·2 microns in a shoulder sample, and 1·4 in a side sample. This also shows that great care must be taken in sampling when average diameters of wool samples from different parts of the body are to be determined.

Crimp in the strands.—The number of crimps of individual fibres composing a strand varied considerably. Also the different strands composing a sample showed a considerable variation in the average number of crimps per fibre (Table 2). Between some of the strands composing a sample there were found differences in the average number of crimps per fibre of 12·4 for a belly sample, 9·8 for a britch sample, 6·1 for a side sample, and 4·5 for a shoulder sample.

Another interesting feature is that the percentage crimp (i.e. the percentage of the straight length taken up by crimp) of the different strands from the same sample may differ. Even strands with the same number of crimps may show an appreciable difference in percentage crimp (Table 2). If in strands the number of crimps remains constant but the percentage crimp varies, there must also be a variation in the type of crimp. Each strand in a sample, apart from being characteristic for the average number of crimps per fibre, may therefore also be characteristic for the type of crimp. Some strands may show a deep crimp, whilst others have a shallow crimp; some may have a large crimp, whilst others have a small crimp.

Each strand in a sample therefore seems to have its own characteristic average number of crimps per fibre, type of crimp, average fibre-length, average fibre-diameter, and number of fibres composing it. It would therefore appear that certain follicle-groups must have characteristic properties of their own, and that there is a tendency for fibres from neighbouring follicle-groups having the same characteristic properties to group together in the formation of strands in the fleece.

General Observations on Strands

Type of crimp.—In Fig. 1 strands are shown with different types of crimp. In (*a*) the strand is shallow-crimped, in (*b*) and (*c*) normally crimped, and in (*d*) partly normally and partly over-crimped. Where wool is inclined to have a shallow crimp, small strands are not so frequent; the existing strands are not clearly defined and so are difficult to isolate. With such wools there is either no tendency for small strands to appear or the shallow crimp does not promote the close combination of fibres to form strands. General observation tends to show that as

the crimp of a strand varies from shallow to deep the strands tend to become smaller and more clearly defined. On the other hand, a small strand may promote the formation of a deeper crimp of the strand itself than a bigger one.

It was also noticed that in the small and over-crimped strands the crimps along the strand had an irregular shape. In some parts the crimps were normal, in other parts they were almost circular; some of them were very deep with flattened sides; in some places there were definite loops, with a tendency to curl at the tips.

Another observation of interest is that the crimps of shallow and normally crimped strands are in the same plane, but those of small, over-crimped strands are not. Barker [12] has also pointed out that the crimps of fibres may lie in different planes.

The small and over-crimped strands are usually found in wool lacking in density. If the covering is inclined to lack density, the follicle-groups in the skin will probably also be sparsely distributed in the skin. One may therefore expect in such cases that the strands produced will be the product of single follicle-groups, or at least of only a small number of follicle-groups. The smallness of the strands in such wools may therefore be ascribed to the sparse distribution of follicle-groups in the skin. In a wool lacking density the strands will be allowed more space to develop the very deep crimps and the loops. The small compact strands will, as a result, have a better chance to develop the different types of crimp associated with them. On the other hand crimpiness is acknowledged as an inheritable property determined by multiple factors. Wool may therefore lack density and yet show no sign of over-crimpiness when the property of being deeply crimped is lacking. One is inclined therefore to ascribe the over-crimpiness found in some wools to the scope allowed an inherent characteristic to develop. In other words, the inherent characteristic of a deep crimp can develop only in the presence of small strands and an open fleece. It is quite possible that some of the beautiful normally crimped wools, much admired by breeder and buyer, would show a decided over-crimpiness if the strands were smaller and the fleece more open. It is indeed a well-known fact that watery wool, characterized by its small compact strands and over-crimped, crêpe-like appearance, is usually found on a belly lacking density of covering, and on sheep carrying a deeply crimped wool.

If fibres are isolated from a wool with a normal depth of crimp, many of them also develop the over-crimped formation, indicating that the density and structure of the fleece may be the factors preventing the fibre-groups from developing the over-crimped formation which is actually inherent in the fibre. There is another indication that normally crimped strands in a dense staple have the tendency to over-crimpiness when the forces keeping it in a fixed position are removed. When a normally crimped strand is removed from the staple and cleaned, first by immersing in ether to remove the fatty substances and then in water to dissolve the salts, the strand will often develop over-crimpiness in parts, very similar to the over-crimped strands found in watery wool [Plate 10, Fig. 2 (*c*)].

Fig. 2 (*a*) shows an over-crimped strand from watery wool, (*b*) a

normally crimped strand, and (*c*) a similar normally crimped strand after immersion in ether and water. This test is, however, not conclusive, as swellings caused by the absorption of water may be the cause of irregular contractions.

Spiral formation.—As stated above, the crimps of the strands of normally and shallow-crimped wools lie in the same plane, but those of over-crimped strands lie in different planes. Observation shows that this is due to a spiral tendency in the over-crimped strands which is lacking in those which are shallow or normally crimped. The spiral is usually found to be reversed at intermittent intervals along the length of the strands. This spiral tendency is probably responsible for the loops and the curly tips of watery wool.

The question also arises whether the spiral tendency is inherent only in the over-crimped strands. Duerden [13] has already pointed out that the tendency to curl is inherent in the locks of the long-woolled British breeds, and also in the birth-coat of the merino lamb. When fibres from normally crimped wool are carefully isolated it will be noticed that they also show the spiral tendency. Further, when a small strand of a normally crimped wool is cleaned with ether and water to remove the binding material, it will be noticed that the spiral tendency also develops [Fig. 2 (*c*)]. The strand marked (*c*) is from a strand similar to (*b*) after first being immersed in ether and then in water. The spiral was flattened out by a glass plate cover, thus showing the big irregular waves. It therefore appears that a strand of wool may, apart from the waves or crimps, also have an inherent spiral tendency.

Watery wool.—Many of the belly-wool samples studied were watery. Typical of watery wool are the small strands, the tendency for the strands to loop, the spiral tendency, the curly tips of the strands, and the general crêpe-like appearance of the wool. Where wool is watery there is usually also a lack of density [10]. It has also been shown by Bartel [14], and in this study, that watery belly-wool may be coarser than the normal shoulder-wool of the same sheep (Table 3). Wateriness cannot, therefore, be ascribed to fibre-fineness.

From what has previously been said it would appear to be possible that the typical characteristics of watery wool can also be inherent properties of normally crimped wool with dense and large strands, in which these properties are prevented from developing on account of the density of the fleece and the size of the strands. For typical watery wool to develop three conditions are apparently necessary: (*a*) the inherent feature of a deep crimp; (*b*) the spiral tendency; and (*c*) considerable lack in density of covering. When (*a*) and (*b*) are present, wool need not show wateriness, as the density of the covering may prevent these features from developing. When (*c*) is present there may also be an absense of wateriness, as the inherent characteristics of (*a*) and (*b*) may be lacking.

The argument is strengthened by the fact that sheep with wool inclined straight may have belly-wool lacking density but yet show no wateriness, whereas watery belly-wool is usually associated with sheep carrying magnificently crimped wool but lacking the density in the

covering of the belly. Sheep are often found having alternately normal and watery belly-wool in successive years, the wateriness then being ascribed to the influence of adverse conditions, such as inadequate nutrition, rearing of lambs, and old age. Such adverse conditions may cause a decrease in the number of fibres per given area of skin surface. One may therefore reason that the same tendency to wateriness was present in the normal belly-wool and that only the density of the fibres

TABLE 3. *Average Diameter of Watery Belly-Wool Compared with that of Normal Shoulder-Wool from the same Sheep (microns)*

Watery Belly	*Normal shoulder*	*Difference*	*Watery belly*	*Normal shoulder*	*Difference*
20·3	15·9	−4·4	24·7	23·5	−1·2
28·4	24·6	−3·8	20·2	19·2	−1·0
20·0	16·7	−3·3	23·9	22·9	−1·0
19·4	16·3	−3·1	17·4	16·4	−1·0
18·0	15·4	−2·6	20·4	19·5	−0·9
16·3	14·0	−2·3	20·1	19·5	−0·6
22·7	20·5	−2·2	20·6	20·0	−0·6
18·6	16·5	−2·1	24·3	23·8	−0·5
23·3	21·5	−1·8	17·9	18·1	+0·2
23·3	21·8	−1·5	21·6	22·0	+0·4
21·4	20·1	−1·3	16·4	17·2	+0·8
18·0	16·8	−1·2	19·3	20·3	+1·0
26·0	24·7	−1·3	23·1	24·7	+1·6
Average for 26 sheep			21·0	19·7	−1·3

Note.—The above table is composed from results obtained by Bartel and the authors.

prevented it from developing. As soon as this obstacle is removed the features typical of watery wool appear. Wateriness in itself may, after all, not be such a bad trait in the fleece of the merino, because it at least indicates an inherent characteristic of a deep crimp. What really is to be deprecated is lack of density. An open belly-wool lacking the features of watery wool must therefore be considered a worse fault from the standpoint of breeding than a watery belly-wool. Wateriness of wool is to be regarded as the result of other faults in the fleece.

Adjustment of Fibre-crimps in a Strand.—When a strand with a deep well-defined crimp is carefully examined, the crimps of the component fibres appear to fit closely into each other [Fig. 1 (*b*) and (*d*), Fig. 2 (*a*) and (*b*)]. If such a strand with a level tip is selected and the fibres isolated, one would expect the fibres to have the same number of crimps corresponding with the number of crimps of the strand. It has, however, previously been shown that the number of crimps in the fibres composing a strand may differ considerably. A study of the distribution of the fibres for crimp shows that the greatest number of fibres usually falls in the class which corresponds with the number of crimps in the strand. This shows that in a strand the largest number of fibres having the same number of crimps, determines the crimp of the strand. Those fibres with more or less crimps have to adjust their crimps according to the

majority of fibres which are similarly crimped. From this it would appear that a considerable proportion of fibres composing a strand do not have a natural but an adopted crimpy formation in the strand. This adjustment of crimp probably takes place soon after the fibres protrude from the skin.

Protective influence of yolk.—When studying the strands from different sheep the protective influence of the yolk on the tips of the strands has been observed. In Fig. 1 (*b*) a strand is shown which had a dark greasy tip, and Fig. 1 (*c*) a strand with a dry tip. In the former the grease made such a good protective covering that the tip looks as if it had just been cut, no difference being apparent between the top and bottom ends of the strand. The tips of the fibres appeared to be as normal as at any other place. The other strand lacked the protective covering and the tip looks frayed. It was also found that the tips of these fibres were either broken or very brittle. The strands with the unprotected tips had much more foreign matter penetrating down the strands than those with the protective covering over the tips. This shows the advantage of a good supply of yolk for protecting the fibre-tips.

Conclusions

Samples of wool, each covering an area of 2×2 cm. of body-surface, were taken from the belly, shoulder, side, and britch of nine merino sheep. From these samples 123 strands were studied for size, average fibre-diameter, average fibre-length, average number of crimps per strand, and type of crimp. The following conclusions were drawn:

1. The strands of wool found in the fleece of merino sheep are probably formed by a grouping of fibres growing from one or more follicle-groups.
2. The strands vary in size in the same sample, on different parts of the body, and on different individuals.
3. The length of fibres composing a strand, as well as the average straight length of the fibres composing individual strands from the same sample, may vary considerably. Also the modes of the distribution-curves based on the length of fibres composing individual strands of a sample may fall in totally different places.
4. The diameters of fibres composing a strand, as well as the average diameter of individual strands composing a sample, show considerable variation.
5. The number of crimps of individual fibres composing a strand varies, as also does the average number of crimps per fibre of the individual strands composing a sample.
6. The percentage crimp (i.e. percentage of the straight length of the fibre taken up by crimp) of different strands from the same sample show differences. Each strand in a sample may be characteristic for its type of crimp.
7. Over-crimpiness of wool may be ascribed to an inherent characteristic developing in the absence of limiting factors, such as density of fleece and large size of strands.

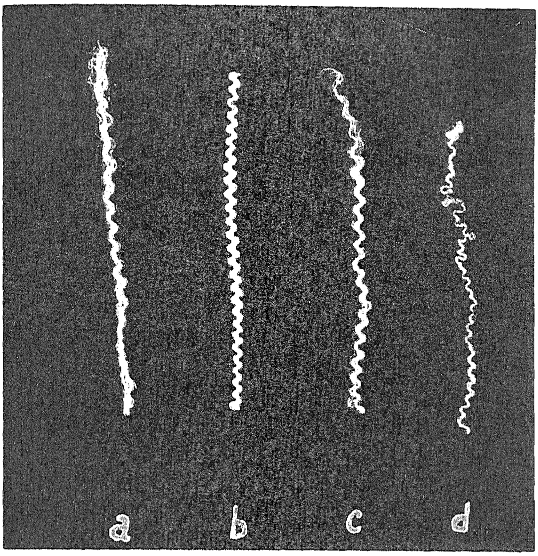

FIG. 1

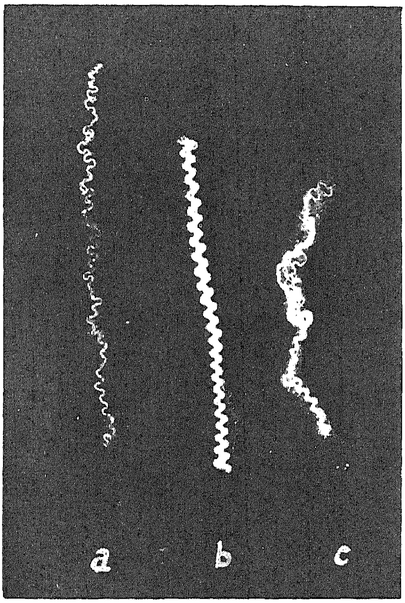

FIG. 2

8. A strand of wool has, besides the crimpiness, probably also an inherent spiral tendency.
9. Wateriness of wool cannot be ascribed to fineness of fibre. For watery wool to develop there is probably necessary the inherent feature of a deep crimp, a spiral tendency, and a considerable lack of fleece-density. Wateriness of wool is due to other faults in the fleece.
10. The largest number of fibres in a strand having an equal number of crimps, determines the crimp of the strand; the other fibres have to adopt the crimpy formation of the majority if the strand is to be compact.
11. A liberal supply of yolk forms an excellent protective covering for the tips of the fibres.

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THE INTERRELATION OF FACTORS CONTROLLING THE PRODUCTION OF COTTON UNDER IRRIGATION IN THE SUDAN WITH SPECIAL REFERENCE TO VARIETY

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Introduction.—In a previous paper [1] Lambert and Crowther have reported the results of experiments, carried out in various localities under the Gezira Irrigation Scheme during the seasons 1932–3 and 1933–4, in which the three factors of sowing-date, nitrogenous manuring, and spacing were compared. These experiments were continued unchanged for a further season by A. R. Lambert and the present author, and the results obtained confirmed, in all respects, the conclusions previously reached [2].

Besides the three factors mentioned, there is another which can be easily controlled in agricultural practice, viz. variety. Up till 1935 the crop grown in the Gezira had consisted almost entirely of Egyptian Sakellaridis; a strain not entirely suitable for local conditions. By this date, however, plant-breeding had progressed sufficiently well to make feasible the replacement of this type by one or more new strains. Among the new types evolved, that known as X1530 appeared particularly promising and, as seed was already available in bulk, a decision was reached by the Sudan Plantations Syndicate to sow a large part of the southern area with this variety in the season 1935–6.

At that time no properly replicated experiments had been carried out on the response of X1530 to variations in the different cultural factors throughout the Scheme as a whole. Such information was obviously desirable. It was therefore decided so to modify the original 'out-station' experiments as to enable varietal comparisons, for various levels of the other factors, to be made. Nitrogenous manuring has so far found little place in local agricultural practice, so this factor was dropped and replaced by a direct comparison between the original Sakellaridis and X1530, the other factors of sowing-date and spacing remaining unchanged. This communication details the results of such experiments, in which various levels of the three factors of sowing-date, spacing, and variety were compared, at three different stations in the Gezira Scheme, during the season 1935–6.

EXPERIMENTAL

Treatments and lay-out.—The individual treatments compared were as follows:

Sowing-date	*Spacing*	*Variety*
1. *Early*, Aug. 7	1. *Close*, 30 cm. between holes.	1. *Sakel*, Gezira main crop; seed from Egypt
2. *Middle*, Aug. 21	2. *Wide*, 60 cm. between holes.	2. *X1530*, Gash seed.
3. *Late*, Sept. 4		

The lay-out and cultural operations were similar to those in the 1933–4 experiments, the 12 treatments being replicated in 5 blocks (60 plots). As previously, the plots of each sowing-date were grouped together in each block. Their positions within the block and their subdivisions for the 4 combinations of variety and spacing were assigned at random.

Notes on localities. The sites of the experiments and their distances in kilometres from the Gezira Research Farm (given in brackets) were (*a*) Umm Degarsi (67 km. N.), (*b*) Barakat (adjoining), and (*c*) Hag Abdullah (47 km. S.).

These experimental areas were sampled to a depth of 6 feet by the Soil Research Section (Agricultural Research Service) at the end of May 1935, and the salient features of their report may be summarized as follows:

(1) The depth at which the salty subsoil is reached increases regularly from north to south (18 in. at Umm Degarsi to 3 ft. at Hag Abdullah). This is associated with decreasing dispersion and pH values, and increasing capillary rises.

(2) Total nitrogen is practically the same for all areas, but there is a concentration in the subsoil in the north and in the surface-soil in the south.

(3) There is a striking increase in subsoil moisture from north to south, which is maintained after making allowance for variable clay-content.

(4) In general, there would appear to be a very decided improvement in soil fertility on passing from north to south, which is in agreement with the normal fertility-gradient in the Irrigated Area.

Rainfall. The rainfall recorded at each station, together with the number of days when measurable rain fell (in brackets), was:

Rainfall (in mm.), 1935

	Umm Degarsi	*Barakat*	*Hag Abdullah*
May	8 (1)	8 (2)	28 (3)
June	40 (5)	31 (1)	11 (5)
July	75 (5)	81 (6)	77 (7)
August	165 (12)	132 (13)	193 (12)
September	4 (1)	40 (6)	48 (7)
October	7 (1)	37 (4)	9 (2)
Total	299 (25)	329 (32)	366 (36)

The distribution of this rainfall is quite normal but the totals are somewhat lower than usual.

Diseases and Pests

Although Black Arm (*B. malvacearum*) was quite negligible, Thrips (*Hercothrips* spp.) caused serious damage in all areas; leaf-shedding was most severe at Hag Abdullah and Barakat, in the order named.

Flea-beetle (*Podagrica puncticollis*) was another serious pest and attacked the early sowings everywhere. That at Barakat was so severely damaged as to result in a serious check to development. American Boll-worm (*Heliothis obsoleta*) caused some bud-shedding everywhere; and there were some slight losses from white ants early in the season at Hag Abdullah and Barakat. Jassids (*Empoasca libyca*) were numerous at Umm Degarsi and had caused much browning and death of the leaf-margins towards the end of the growing-season.

Leaf-curl on the Sakel (X1530 is highly resistant) did not develop at all until late in the season and can have had little or no effect on the final yields.

FINAL YIELDS

The final yields of seed-cotton for the separate stations are given in Table 1. The treatment-yields are given in columns under the headings of the respective experiments.

TABLE 1. *Final Yields of Seed-cotton (kantars per feddan*)*

Treatments			*Stations*			
Sowing-date	*Spacing*	*Variety*	*Umm Degarsi*	*Barakat*	*Hag Abdullah*	*Average all stations*
Aug. 8–12	30 cm.	Sakel	4·57	4·01	8·43	5·67
	30 cm.	X1530	5·77	5·73	10·65	7·38
	60 cm.	Sakel	3·76	3·81	7·80	5·12
	60 cm.	X1530	5·68	5·11	9·90	6·89
	Average		4·94	4·66	9·19	6·26
Aug. 22–6	30 cm.	Sakel	4·42	4·16	7·25	5·28
	30 cm.	X1530	5·67	5·86	9·06	6·86
	60 cm.	Sakel	3·55	3·96	4·35	3·95
	60 cm.	X1530	5·69	5·52	7·96	6·39
	Average		4·83	4·87	7·15	5·62
Sept. 4–7	30 cm.	Sakel	4·38	4·17	5·27	4·61
	30 cm.	X1530	5·57	4·80	5·93	5·43
	60 cm.	Sakel	3·24	3·52	3·06	3·27
	60 cm.	X1530	5·26	4·78	4·20	4·75
	Average		4·61	4·33	4·61	4·52
Average all treatments			4·79	4·62	6·98	5·47

* 1 kantar = 312 lb. = 141 kg. 1 feddan = 1·038 acres = 0·420 ha.

Table 2 gives a summary of the significant treatment-responses at the separate stations, and the results of the complete analysis, taking all stations together, are presented in Table 3.

TABLE 2. *Summary of the 'Significant' Treatment-Differences at the Separate Stations*

	Umm Degarsi	*Barakat*	*Hag Abdullah*	*All*
Sowing-date	S	S	SS	SS
Spacing	SS	S	SS	SS
Variety	SS	SS	SS	SS
Sowing and spacing	..	..	S	..
Sowing and variety	..	..	SS	SS
Spacing and variety	SS	..	..	S
Sowing, spacing, and variety	..	..	..	..

Note.—'S' = the experimental z value exceeded the 5 per cent. probability value.
'SS' = the experimental z value exceeded the 1 per cent. probability value.

TABLE 3. *Analysis of Variance of All Stations*

	Degree of freedom	*z value*	*Significance*
Blocks	4	. .	. .
Sowing-date	2	1·799	SS
Remainder 1	8		
Spacing	1	2·138	SSS
Variety	1	2·845	SSS
Sowing and spacing	2	(0·437)	. .
Sowing and variety	2	0·999	SS
Spacing and variety	1	0·990	S
Sowing, spacing, and variety	2	(0·218)	. .
Remainder 2	36		
Place	2	2·169	SSS
Place and sowing	4	1·550	SSS
Place and spacing	2	0·781	S
Place and variety	2	. .	. .
Place, sowing, and spacing	4	. .	. .
Place, sowing, and variety	4	. .	. .
Place, spacing, and variety	2	. .	. .
Place, sowing, spacing, and variety	4	. .	. .
Remainder 3	96		

Note.—'S' and 'SS' as above in Table 2. 'SSS' denotes that the experimental z value very greatly exceeded the 1 per cent. probability value.

RESULTS

The various factorial effects and interactions described in the succeeding sections refer to the complete analysis, in which the results from all three stations are grouped together and analysed as one unit. Place thus becomes one of the factors analysed. Further, any conclusions reached will be of more or less general application: the extent to which such results are dependent on those from a single station will, however, be indicated.

(1) *Effects of Single Factors*

The effects of the single factors are obtained by summing yields for all treatments in which a particular factor is maintained at the same level irrespective of the levels of the other factors. The results of the four single-factor comparisons, all of which are highly significant, are given in Table 4.

TABLE 4. *Yields of Single Factors* (*kantars per feddan*)

Sowing-date		*Spacing*		*Variety*		*Place*	
Aug. 8–12	6·26	Close	5·87	Sakel	4·65	Umm Degarsi	4·79
Aug. 22–6	5·62	Wide	5·06	X1530	6·28	Barakat	4·62
Sept. 4–7	4·52					Hag Abdullah	6·98

Sowing-date.—The yields corresponding to the various sowing-dates fall off progressively with lateness, the effect being most marked at Hag Abdullah. The early sowing at Barakat yielded slightly less than the middle sowing (see Table 1), but this result is fully explained by the abnormal flea-beetle damage, so that there must have been a real optimum for the whole area at or before the earliest sowing-date.

Spacing.—Close spacing once again demonstrates its general superiority over wide spacing.

Variety.—The result of the varietal comparison is most striking, since the X1530 shows an overall increase of 35 per cent. on the Sakel. This is very satisfactory and holds out great hope for the eventual replacement of Sakel by X1530, or a similar variety, throughout the area of the Gezira Scheme. In passing, it may be noted that the superiority of the new variety is maintained under all conditions, since there is not a single case in which it fails to yield better than Sakel, provided the levels of the other factors are maintained the same.

Place.—The average yield of the Hag Abdullah experiment is very significantly better than those of the other two stations. Though somewhat at variance with some of the previous season's results, the present result is in agreement with the general fertility-trend of the Irrigated Area, and confirms the conclusions based on soil sampling. Furthermore it seems probable that, but for the abnormal damage to the earliest sowing, the average yield of the Barakat experiment would have been intermediate in position between the other two.

(2) *First Order Interactions*

The interactions of the different pairs of factors are presented in Tables 5 to 10. All yields are expressed in kantars per feddan.

(*a*) *Sowing-date and Spacing*

TABLE 5. *Interaction: Sowing-date and Spacing*

	Sown Aug. 8–12	*Sown Aug. 22–6*	*Sown Sept. 4–7*
Spacing 30 cm.	6·52	6·06	5·02
Spacing 60 cm.	6·00	5·16	4·02

Although not significant, the interaction displayed is normal in type, since close spacing shows an increasing superiority over wide as the sowings become later. The interaction reaches significant levels at Hag Abdullah only.

(*b*) *Sowing-date and variety*

TABLE 6. *Interaction: Sowing-date and Variety*

	Sown Aug. 8–12	*Sown Aug. 22–6*	*Sown Sept. 4–7*
Sakel	5·39	4·61	3·95
X1530	7·13	6·62	5·09

The interaction is highly significant and takes the form of a relatively greater yield of X1530 at the middle sowing-date. Although this result occurs at all the stations, its interpretation remains somewhat obscure, but from other information that is available it seems possible that the optimum sowing-period for X1530 may be rather later than that for Sakel.

(*c*) *Spacing and variety*

TABLE 7. *Interaction: Spacing and Variety*

	Spacing	
	Close	*Wide*
Sakel	5·18	4·12
X1530	6·56	6·01

The figures indicate a greater increase in yield of X1530 over Sakel with wide spacing. This is clearly the outcome of the difference in habit of the two varieties; the greater lateral-branch production of X1530 allowing of better compensation with wide spacing.

(*d*) *Place and sowing-date*

TABLE 8. *Interaction: Place and Sowing-date*

	Sown Aug. 8–12	*Sown Aug. 22–6*	*Sown Sept. 4–7*
Umm Degarsi	4·94	4·83	4·61
Barakat	4·66	4·87	4·33
Hag Abdullah	9·19	7·15	4·61

The much more marked effect of sowing-date at Hag Abdullah is obvious from the table.

(*e*) *Place and spacing*

TABLE 9. *Interaction: Place and Spacing*

	Spacing	
	Close	*Wide*
Umm Degarsi	5·06	4·53
Barakat	4·78	4·46
Hag Abdullah	7·76	6·21

As with sowing-date, there is again a much greater response to spacing shown at Hag Abdullah. The significance of both these interactions appears to be determined almost entirely by the results from this one station. In general, factorial responses in the southern area would seem to be always more marked than in the centre or north.

(f) Place and variety

TABLE 10. *Interaction: Place and Variety*

	Sakel	*X1530*
Umm Degarsi	3·98	5·60
Barakat	3·94	5·30
Hag Abdullah	6·02	7·94

The interaction effect is here quite negligible, although the figures do indicate a slightly greater relative superiority of X1530 over Sakel in the north. This result is all the more remarkable when it is realized that the generally accepted opinion in the Gezira is that the former variety does relatively better in the south than in the north, although prior to the present experiments no adequately controlled tests had been carried out.

(3) *Higher Order Interactions*

These are all entirely negligible and therefore need not be considered.

DISCUSSION AND CONCLUSIONS

(*a*) *Effect of disease-damage on yield.*—The season under review proved to be extremely favourable for experimentation in more than one respect. Not only was the growth of the crop good, but the negligible amount of damage from Black Arm and Leaf-curl recorded at the different stations allows of a comparatively clear-cut interpretation of the interactions of the remaining diseases and pests.

The effects of Thrips-damage is clearly important in relation to sowing-date. Adult insects migrate on to the cotton towards the end of October or the beginning of November. Initially the density of infestation is practically the same for all treatments, so that, even if there was no subsequent alteration in their relative numbers, they would cause relatively greater damage to the smaller plants of the later-sown cotton. This uniformity of infestation does not, however, persist, since conditions on the later sowings appear to be more favourable to the development of the pest. Thus both the absolute as well as the relative severity of attack is greatest on the late sowings, so that the most important effect of Thrips-damage is to increase the inferiority of these sowings. In particular, the very marked sowing-date effect at Hag Abdullah must owe much of its magnitude to the very heavy Thrips-infestation in that area. At Barakat, on the other hand, it would appear probable that the effects of Thrips-damage on the late sowings was more than offset by the heavy Flea-beetle damage on the earlier sown cotton.

Interaction of Thrips-damage and spacing appears to be practically non-existent but, as far as they can be trusted, visual comparisons on leaf-samples give the impression that there is slightly more damage with close spacing, which would seem to be at variance with the conclusions

reached previously by Lambert and Crowther [1]. The discrepancy is, however, only apparent. The present observations are based on equal plot-areas, whilst those of Lambert and Crowther refer to individual plants. Re-examination of their original data showed that, when the greater number of plants per unit area is taken into consideration, there were actually more leaves damaged on the close-spaced treatments.

The interaction with variety appeared to be more marked, X1530 showing rather more damage than Sakel.

Mention must be made of the leaf-margin damage as a result of Jassid-attack, which is so striking a feature of the northern Gezira, although, at the time of writing, little information is available regarding its effect on the final yields. The browning and death of the leaf-margins only become evident towards the end of the main growing-period, when the plant has already begun to mature its main crop of bolls, so that it is quite possible for some kind of internal compensation to occur. This might possibly take the form of a withdrawal of food materials from the injured areas to meet the needs of the developing bolls, whilst the uninjured portions of the lower leaves remain active longer than normal, and thus compensate for the loss of assimilatory area higher up the plant.

Summarizing the above, it appears probable that, during the present season, disease and pest-damage can have made little difference to the relative order of final yields except in the earliest sowing at Barakat. On the other hand, it is evident that disease can play a large part in determining the magnitude of the various factorial effects, and this must always be borne in mind when attempting to draw conclusions from an experiment of the present type.

(*b*) *Agricultural value of the results.*—The main point brought out by previous experiments of this nature has been the importance of close spacing to obtain the maximum yields with late sowings. This is abundantly confirmed by the present results, which actually show a maximum yield with close spacings at all sowing-dates. This is to some extent a seasonal effect, since in the present season the optimum was undoubtedly early, but the results do clearly indicate the advantages of a comparatively close spacing in agricultural practice.

Sowing at a fixed date is unfortunately most difficult on account of rain and lack of sufficient labour over an area as big as that covered by the Gezira Scheme. Even if this was possible, the results, taken over a series of years, show sufficient season fluctuation in the optimum to render it impossible to fix this date with any exactitude. Two conclusions do, however, emerge: (1) that there is almost no chance of obtaining maximum yields from cotton sown later than the middle date of sowing used in these experiments; and (2) the more marked importance of sowing early in the south, as demonstrated by the Hag Abdullah results.[1]

The results of the varietal comparison are most important, and the striking superiority of X1530 over Sakel has been clearly demonstrated

[1] The earliest sowing at this station failed to give the highest yield in 1934–5. Yields of all sowings, however, were very high and sowing-date differences were not significant.

under all the conditions tested. Further, there is no evidence to suggest that X1530 is not suitable for the northern areas and, provided its lint-quality is satisfactory, there seems no reason why it should not replace Sakel over the whole Irrigated Area. In this connexion, it is noteworthy that the expert classifiers of the Sudan Plantations Syndicate graded the experimental pickings of X1530 slightly higher than Sakel.

Summary

Field experiments are described in which the new variety X1530 was compared with Sakellaridis under certain of the cultural conditions associated with the Gezira Irrigation Scheme.

Experiments were carried out on three different sites, representative of the north, centre, and south Gezira. In each experiment comparisons were made of varieties, sowing-dates, and spacings in different combinations.

X1530 proved markedly superior to Sakel under all the conditions tested, and gave a 35 per cent. greater yield of seed-cotton. The interaction of place and variety was quite negligible.

The importance of close spacing to obtain maximum yields was again brought out, and this confirmed the conclusions obtained from earlier experiments.

The optimum sowing-date exhibited the usual seasonal variation when compared with other years, but the more marked importance of early sowing in the south, in order to obtain maximum yields, appears to be established.

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THE EFFECT OF MANURES ON THE SIZE OF MAINCROP POTATOES

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SINCE the establishment of the Potato Marketing Board in 1934, the question of the size of potato tubers intended for sale has assumed added importance, for the size of the riddle used to determine what shall be classed as ware potatoes is now prescribed by this authority. Growers on any but the richest soils generally set out to obtain as bold a sample as possible, and in these circumstances all factors affecting the size of potato tubers are worthy of study.

The relation between the size and treatment of the 'seed' and the size of the tubers of the resulting produce has been examined by Bates [1], Brandeth [2], and others, but the effects of manuring have seldom been studied in detail. A recent summary [3] of results obtained at Rothamsted drew attention to this question. In the following paper these Rothamsted data together with subsequent results are collected and discussed.

Although the potato has been the subject of more manurial experiments than any other root crop, the percentage of tubers classed as ware has by no means always been recorded, and even when recorded the figures have not received much comment. Nevertheless, the early experiments provide ample evidence to show that manurial treatment does influence the size of the tubers and a few of these experiments are collected below.

At Rothamsted [4] a series of fertilizer plots were laid down on Hoosfield in 1876 and continued till 1901. The percentage of ware tubers for certain treatments averaged over the 26-year period was:

Percentage of Ware, 1876–1901

	No Minerals	*Minerals (PK)*	*Mean*
No nitrogen	82·8	89·9	86·4
Sulphate of ammonia	82·1	88·5	85·3
Nitrate of soda	85·1	88·7	86·9
Mean	83·3	89·0	

The most pronounced effect is that due to minerals, and since the effect of superphosphate was shown to be small in other plots in the same series, it may be inferred that the chief active constituent of the mineral mixture was potash.

From the well-known and extensive series of potato experiments carried out by the County Instructors under the Irish Department of Technical Instruction [5], the following figures may be derived:

Mean of 353 Centres, 1901–1911

Manuring per acre	*Total crop tons*	*Percentage ware*
None	4·00	71
15 tons dung	8·20	83
20 tons dung	9·10	83
15 tons dung (D)+1 cwt. sulphate of ammonia (N)	9·15	83
D+N+4 cwt. superphosphate (P)	9·95	83
D+N+P+1 cwt. muriate of potash	10·85	85

A marked increase in ware was produced by the first dressing of dung, and there was a slight indication of a further improvement for potash.

A further series was undertaken by the University College of North Wales in the years 1908–11 for which detailed results have been published [6]. The following figures have been calculated from these data for a few of the treatments tested:

Mean percentage ware on unmanured land	*Mean percentage ware with manures*		
	Dung	*NPK*	*Dung+NPK*
1 expt. 44·9	63·4	70·4	82·1
3 expts. 56·4	78·6	80·4	76·1
1 expt. 68·7	74·9	69·6	75·1
7 expts. 74·4	81·5	86·0	85·3
6 expts. 86·9	84·6	87·4	86·4
8 expts. 93·6	94·1	93·1	92·6

Complete manuring either with dung, fertilizers, or both, had a considerable effect on the size of the potatoes, and this effect was much more marked when the unfertilized crop had a low proportion of large tubers.

Bescoby [7], in a review of the results of potato experiments carried out at many centres in Great Britain, reports that increases in percentage ware have been recorded as the result of the use of farmyard manure, artificials, and so far as the individual nutrients were concerned, potash and superphosphate. Bates [1] states that nitrogen has been shown on numerous occasions to have a beneficial effect on size of produce.

The data used in this survey consist of the results of 40 potato experiments carried out in the years 1934–6 at Rothamsted, Woburn, and at various outside centres. All are published in full in the Annual Reports of the Rothamsted Experimental Station [8]. The effects of nitrogen, phosphate, and potash have been studied individually and in combination; alone, and in conjunction with farmyard manure. Many of the trials were designed to test fertilizer effects at three or more levels. In some instances organic sources of nitrogen, such as dried poultry manure, rape-cake, and fish-meal, were included. A range of soil types has been covered, sands, gravels, loams, limestones, and clays being represented in the mineral series, whilst in the fenland class light peaty fens and strong fens containing much clay have each carried several experiments. Most of the common varieties of maincrop potatoes grown commercially have been included.

The size of the riddle used for ware-determination has usually been that prescribed by the Potato Marketing Board for the crop in question. In a few cases the potatoes were sorted by hand, and at several centres size of riddle was unspecified.

The mean yield and mean percentage ware are grouped below (Table 1) for each size of riddle. The yields are in descending order in each class.

TABLE 1. *Mean Yield and Mean Percentage Ware*

Soil	*Variety*	*1½ in. Riddle* Mean yield tons	*1½ in. Riddle* Mean ware %
Sandy	Great Scot	11·36	85·1
Light loam	Kerr's Pink	10·44	77·6
Heavy Fen	Majestic	9·05	93·9
Clay	King Edward	8·87	88·2
Light Fen	Majestic	8·83	84·8
Gravelly	King Edward	8·71	63·9
Light Fen	Majestic	7·84	87·4
Medium loam	Great Scot	7·10	90·5
Limestone	King Edward	6·04	63·8
Light Fen	Majestic	5·81	75·5
Limestone	King Edward	5·25	79·9
Heavy Fen	Majestic	3·47	79·1
Gravel	King Edward	2·80	59·8

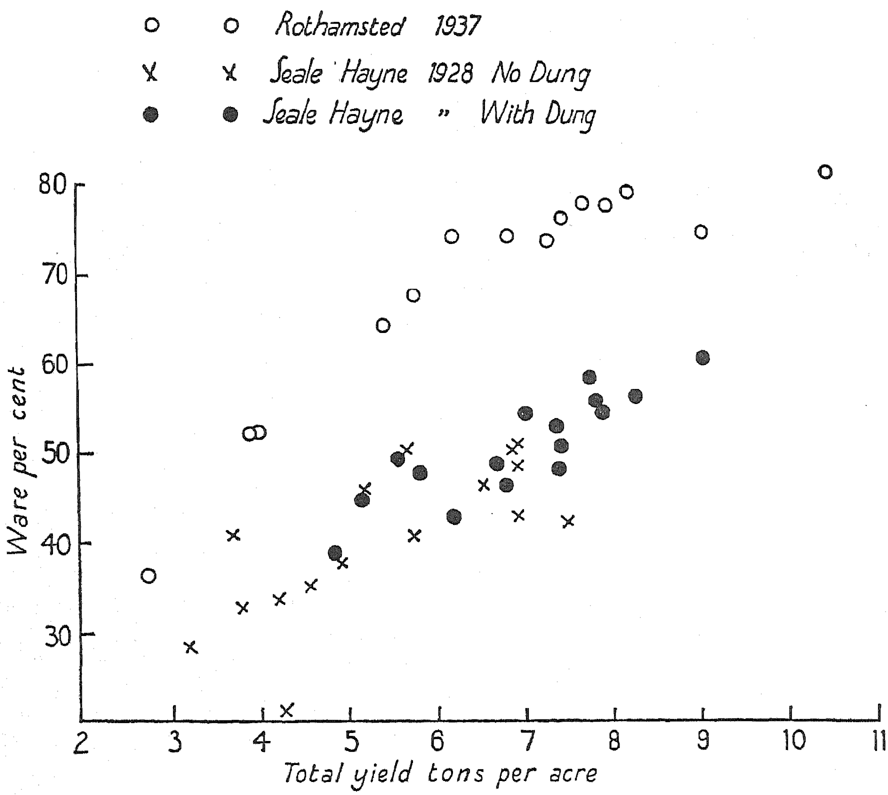
Soil	*Variety*	*1⅝ in. Riddle* Mean yield tons	*1⅝ in. Riddle* Mean ware %
Light Fen	King Edward	9·49	61·7
Light Fen	Majestic	8·40	85·8
Sandy	Majestic	8·08	76·3
Light Fen	Majestic	7·14	73·3
Heavy Fen	Majestic	6·80	82·4
Sandy	Eclipse	5·94	67·1

Soil	*Variety*	*1¾ in. Riddle* Mean yield tons	*1¾ in. Riddle* Mean ware %
Light Fen	Kerr's Pink	9·03	82·2
Clay loam	Ally	7·93	86·4
Sandy	Ally	7·07	78·5
Clay loam	Ally	6·83	70·8
Clay loam	Ally	6·75	74·3
Clay loam	Ally	6·67	73·2
Clay loam	Ally	6·29	77·6
Clay loam	Ally	4·51	64·6

The pairs of values show very little connexion. Quite different results were obtained from the same variety when grown on different soils, and also from different varieties when grown on similar soils. Great Scot, for example, gave 90·5 per cent. of 1½ in. ware on a medium loam with a comparatively low yield of 7·10 t., whilst on a sandy soil with the high yield of 11·36 t. the same variety gave only 85·1 per cent. Two yields with King Edward were practically equal, but on a clay soil there was 88·2 per cent. ware, and on gravel there was only 63·9 per cent. On light fen soils King Edward gave considerably less 1⅝ in. ware than Majestic. Although these effects are large and commercially important they are outside the scope of the experiments under review, since the series was designed to test fertilizer effects only. When soil, season, and variety are kept constant as in a single experiment, the relationship between total yield and percentage ware comes out more clearly. In Fig. 1 are plotted the results of two experiments showing a wide range of responses to manurial treatment. The experiment with the higher yield-values was carried out at Rothamsted in 1935, the other at Seale Hayne College in 1928 [9]. Both experiments show that not only the total yield but also the size of the potatoes is greatly influenced by manurial treatment, and that a close relationship exists between the yield and the corresponding percentage of ware tubers. At Seale Hayne the percentage ware increased fairly uniformly throughout the whole range of yield values. At Rothamsted, with

higher values both for yield and ware, there was some indication that the yield increased more rapidly than the percentage ware at the higher levels.

The falling off in the rate of increase in percentage ware with increasing size may be illustrated in another manner using the whole body of data from the experiments. The primary tables showing the effects of the three common nutrients and two classes of organic manures on yield



Relationship between total yield of potatoes and percentage ware.

and ware are grouped in the Appendix (Tables I–IV). When the actual increases in percentage ware due to each class of manure are grouped according to the size of the original tubers as measured by the percentage ware without the nutrient in question, Table 2 is obtained.

The Table shows that in the Rothamsted experiments samples with ware grading above 90 per cent. or below 60 per cent. of the total produce were rather unusual. The former class showed negligible improvement in size on the average, no matter what the manurial treatment may have been; the latter class usually showed striking responses in tuber-size to the addition of almost any nutrient. The intermediate grades take up a middle position. Although the experimental material on which the figures for each nutrient are based is not necessarily the same in respect of centres or numbers of experiments, the larger average responses

obtained for potash and for dung suggest that these manures are particularly effective in increasing the size of potatoes. The effects are examined in more detail below.

TABLE 2. *Percentage Ware*

Mean effects of nutrients and organic manures grouped according to initial percentage ware

Initial percentage ware (no manure)	*Increase due to*						*Total Expts.*
	N	*P*	*K*	*Organic*	*Dung*	*NPK*	
Over 90	−0·4	−1·1	+0·6	−0·3	..	..	9
80	+1·2	−1·1	+1·5	+0·7	..	..	34
70	+2·6	+3·6	+8·7	−1·0	+5·5	+4·0	29
60	+0·7	+6·8	+8·4	+2·8	+15·2	+4·4	29
50	+16·8	+5·9	+15·8	..	+25·9	+22·4	9
Under 50	..	..	+20·3	..	+34·2	..	3
Weighted mean	+2·0	+2·1	+7·6	+1·2	+15·3	+6·9	113

Effect of Sulphate of Ammonia (Table I, Appendix).—This fertilizer was tested in 34 experiments, 5 having a basal dressing of dung. In 13 of the trials sulphate of ammonia was used at two rates of dressing. The effect on total yield was very pronounced; at all centres except one it was positive and in 23 of the experiments it was statistically significant. Sulphate of ammonia had on the whole a beneficial effect on percentage ware but its action was not so consistent as on total yields. In 23 experiments the percentage ware was increased and 9 of these increases were significant; in the remaining 11 experiments the ware values were less in presence of sulphate of ammonia than in its absence, but none of these apparent depressions were in themselves significant. In the 9 experiments showing definite increases in size of tubers there were also definite increases in total yield.

Of the individual centres the fenland soils show points of interest. The heavy fens gave considerable increases in the total crop for added nitrogen, and the percentage ware was slightly increased. The light fens appear to be less responsive, the effect on yield was only moderate and the change in ware was frequently negative. At centre 19, a very light blowy fen on peat, nitrogen benefited the yield only slightly, and the ware seemed if anything to be depressed in spite of a very low value without nitrogen. It will be seen later that the outstanding need of this particular soil was potash.

Effect of Superphosphate (Table II, Appendix).—At all centres superphosphate was the source of phosphoric acid tested. At one only, No. 15, basic slag was compared with superphosphate, and in this experiment slag was significantly inferior to superphosphate both in respect of yield and size of tubers.

There were 23 experiments, three having a basal dressing of dung. In all cases except one the effect of superphosphate on yield was positive. It was statistically significant in twelve instances. The general effect on the size of tubers was also positive but there was a slightly higher proportion of negative values than was observed with nitrogen, and one of

these depressions was in itself significant. The figures were 15 increases in percentage ware, 2 significant; 8 decreases, 1 significant. Superphosphate is commonly regarded as the leading nutrient for use on fenland soils, and in the experiments under review it has certainly given very good results on the black-land farms. Phosphate has, however, done somewhat better on the heavier than on the lighter class of fenland. Some of the light fenland centres, Nos. 8 and 14, proved relatively unresponsive to superphosphate. The effects on ware, though never very marked, were at least as good on the light as on the heavy fens. On one of the light fen farms, No. 9, the lower level of superphosphate, approximately $4\frac{1}{2}$ cwt. per acre, was sufficient, the double dressing having no further effect on yield and also depressing the size of tubers. The largest effect of phosphate on tuber-size was observed on a heavy organic 'moss' soil in south Lancashire, No. 15, where the increase in ware was no less than 18·3 per cent.

Effect of Potash (Table III, Appendix).—At all centres except two sulphate of potash was used. There were 22 experiments, all but 2 giving increases in yield due to potash, 11 of them sufficiently large to be statistically significant. The effect of potash on percentage ware was much more marked and consistent than that of nitrogen or phosphate. Thus the average increment due to potash was +7·6 per cent., the corresponding figures for nitrogen and phosphate being +2·0 and +2·1 per cent. respectively. In only 4 out of the 22 trials did potash appear to depress the ware, three of these depressions were quite trivial, but the fourth, No. 14, was real, though it only occurred on the plots without nitrogen and would therefore not have operated under normal circumstances. In 9 of the experiments potash increased both ware and yield significantly. Examination of the effects in presence and absence of dung shows that on the whole potash was most effective when dung was absent. None the less at a Warpland centre, No. 21, potash increased both yield and ware significantly in presence of dung.

Although potash is generally stated to be most effective on light soils it will be noted that even on the heavy clay loam at Rothamsted, Nos. 1–4, 9 and 16, potash showed substantial increases either in total crop, ware, or both. On the strong fenland, Nos. 5 and 11, potash appeared to be quite unnecessary even in the absence of farmyard manure. The most conspicuous effect of potash was found on the light fen soils in the absence of dung where increases in ware of over 22 per cent. were recorded (Nos. 10 and 12).

Effect of Dung (Table IV, Appendix).—The extra labour required in applying dung to a number of small randomized plots has greatly restricted the number of replicated experiments in which it is possible to assess the effects of farmyard manure alone and in combination with other nutrients. Only three of this kind are available for the purpose in view, two carried out at Rothamsted on a clay loam, the remaining one on a light fenland soil near March. Evidence derived from the earlier County Experiments and presented in the introduction has shown that dung is extremely effective both in increasing yield and tuber-size. The modern series amply confirms this, and has the additional advantage of

indicating how the action of dung is influenced by the presence of artificial fertilizers.

Of the 12 comparisons taken out in Table IV no less than 10 show significant increases due to dung in both yield and tuber size. Some of the figures are remarkable; thus at Rothamsted, No. 1, when the basal dressing consisted of sulphate of ammonia only, dung increased the ware by 34 per cent. The mean effect of dung on ware over all the comparisons is +15·3 per cent. There is a marked relationship between the effectiveness of dung and the presence and absence of potash, seen most clearly at the centre on light fenland, No. 2:

	Dung effect	
Plots without potash . .	Total crop +51·8%	Ware +29·7%
,, with potash . .	,, ,, +17·3%	,, +3·6%

An additional point came to light in the Rothamsted experiments of 1935 and 1936. One of the experimental treatments involved the manner of applying dung, either spread and ploughed in in autumn or put in the ridges in spring. In each experiment dung did better both on yield and proportion of ware when applied in the ridges.

	Excess of dung in ridges over dung spread	
	Yield, tons	*Ware, %*
1935	+*0·91* ±0·191	+0·7 ±0·972
1936	+*1·88* ±0·354	+*4·5* ±1·72

Effect of Organic Nitrogen (Table V, Appendix).—The manures tested were dried poultry manure, in 11 experiments, with malt culms, fishmeal, and rape-cake as comparative treatments in certain cases. All plots were equalized in total phosphate and potash, so that only the nitrogen effect and any possible benefit from the organic matter was measured. No fenland centres were included in this series. So far as yield was concerned each of the 15 comparisons gave positive increments for organic nitrogen, and 9 of these increments were statistically significant. Eight of the comparisons gave increases in ware, of which 4 were significant. Seven experiments gave decreases. Eleven experiments furnished comparisons of organic manures and sulphate of ammonia in equivalent nitrogen; the mean values were:

	Increases, mean of 11 experiments	
	Yield, tons	*Ware, %*
0·6 cwt. N as organic manures . .	+1·0	+0·4
,, ,, sulphate of ammonia .	+1·6	+1·6

The magnitude of the yield-effects was lower than that given by nitrogen in the form of sulphate of ammonia; and the effects of organic manures on size of tubers were also slightly less.

Effect of Complete Artificials (Table VI, Appendix).—Seven of the experiments yield information in regard to the effect of 'balanced'

mixtures of artificial fertilizers, 3 in absence of dung and 4 with a basal dressing of dung. The artificials consisted of sulphate of ammonia, superphosphate, and sulphate of potash. Five experiments tested artificials in increasing dressings. At one of the centres on a light loam generous dunging alone gave maximum yields both in 1935 and 1936, additional artificials produced negligible effects. In the remaining 5 experiments the increases in yield were substantial, and moderate and significant increases in percentage ware resulted. At Rothamsted, Nos. 1 and 4, 12 cwt. of artificials increased the total crop by 5·1 t., and the ware by 22·4 per cent. when used without dung. In presence of dung the corresponding figures were 4·2 t. and 7·1 per cent.

Curvature.—Several of the experiments were designed to test the effect of nutrients at two or more rates of application, thus giving some indication of the shape of the response curve. This aspect of fertilizer action is important in practice when deciding what is likely to be the most profitable level of manuring to adopt. In experiments involving two rates of application of a nutrient, i.e. no fertilizer (F_0), single (F_1), and double (F_2), the conventional measure of the curvature is given by the excess of the extra response to the second dressing over the response to the first, or $F_2-F_1-(F_1-F_0)$, where the symbols represent the yields corresponding to the fertilizer dressings. On this basis a negative sign for the curvature means that the extra response to the second dose of nutrient was less than the response to the first. Zero curvature indicates a strict proportionality between fertilizer application and crop-yield. A positive value for the curvature is obtained when the extra response to the second dressing is greater than the response to the first. Most of the experiments reported in the Appendix tested single and double dressings only, but a few involved a larger number of levels of application and similar expressions have been calculated for them.

In examining the nature of the curvature it is permissible to confine attention to those experiments in which the effects are large. The data include 15 trials in which fertilizers gave statistically significant effects both in yield and in percentage ware. The signs of the curvature terms in this series were as follows:

	Negative		*Positive*	
	Total	*Significant*	*Total*	*Significant*
Curvature for yield . .	13	5	2	0
,, ,, percentage ware	14	3	1	0

At the rates of dressing chosen in these experiments the increment in yield per unit fertilizer was almost always smaller at the higher than at the lower rate of application. Yield and ware both behaved similarly in this respect. Since the actual quantities of manure used per acre in these experiments were quite normal, in the single and double experiments, for example, the first dose represented a medium agricultural application and a double dose a generous but in no way excessive one, it appears that the falling off in effectiveness at the higher levels can be regarded as the common form of behaviour in practice. It should be

emphasized, however, that although the extra effect of a double dressing may be less than a single one yet the full dressing may still be, and frequently is, highly profitable and justified.

Interactions.—It is often claimed that fertilizers do better when used in combination than when used individually. The experiments under review yield some information on this point in respect of yield and percentage ware. Taking the interactions of the three common nutrients first, there are 30 instances of the mutual effect of these nutrients taken in pairs. The conventional measure of the interaction between a pair of nutrients, say N and K, is given by

$$\tfrac{1}{2}(O+NK-N-K).$$

If this quantity is positive the nutrients have a greater effect in combination than the sum of their separate effects; if the quantity is zero the manures act quite independently, if negative the combined effect is less than the sum of the individual effects. It will be sufficient to note the signs of the above 30 interactions; they are as follows:

	N×K		*N×P*		*P×K*		*Total*	
	+	−	+	−	+	−	+	−
Yield . . .	7	3	7	4	6	3	20	10
Percentage ware .	7	3	5	6	7	2	19	11

Of the 30 sets of values the effect for yield and for ware had the same sign in 25 cases. The actual magnitude of the interaction-effects on yield and tuber size were usually small. Two of the PK results on yield and one of the effects on ware were in themselves significant. That on ware was negative and its nature is shown by the following figures:

	Ware %±2·56
No N, no K . .	76·5
N only . . .	90·8
K only . . .	88·1
N+K . . .	90·5

Interaction $\tfrac{1}{2}(90{\cdot}5+76{\cdot}5-90{\cdot}8-88{\cdot}1) = -6{\cdot}0\pm2{\cdot}56$

Each manure used separately gave a large increase in ware but the combination produced no further increase. The interactions of nutrients with farmyard manure are more important and show several points of interest. They are set out in Table 3.

TABLE 3. *Interactions Involving Farmyard Manure*

Soil	*Yield, tons* *K×D*	*(PK)×D*	*S.E.*	*Ware, per cent.* *K×D*	*(PK)×D*	*S.E.*	*Basal dressing*
Light Fen .	*−0·84*	..	±0·286	*−10·8*	..	±3·19	No N
,, ,, .	*−1·61*	..	±0·286	*−15·2*	..	±3·19	With N
Heavy loam.	..	−0·30	±0·382	..	*−6·7*	±1·95	No N
,, ,, .	..	*−1·75*	±0·493	..	*−17·4*	±2·25	With N

The most marked effects occur when dung is used in presence and absence of potash. The interaction is strongly negative in both experiments bearing on this point, and affects yield and percentage ware in a similar manner. The magnitude of the negative dung and potash interaction appears to be linked up with the presence or absence of nitrogen. Thus in every comparison the interaction is more negative in the presence of nitrogen than in its absence. This may be expressed in agricultural terms as follows: Potash reduces the dung effect, and this reduction is more pronounced when all plots receive nitrogen.

Summary

The results of 40 fertilizer experiments on potatoes carried out under widely different conditions are collected to show the influence of manures on the percentage of tubers classed as ware. The corresponding yield-effects are also tabulated. The data show that the action of fertilizers on tuber-size is frequently considerable and statistically significant. Large effects on percentage ware due to fertilizer action occur chiefly in crops where the initial percentage was low. When variety and soil condition are constant there is a fairly close positive relationship between yield and percentage ware: manurial treatments which give high yield also tend to give a high proportion of large tubers. Of the three common nutrients, potash stands out in its strong effect in increasing tuber-size; nitrogen and phosphate were each beneficial but the effect of each was much less than that of potash. Dung had a considerably greater effect on tuber-size than other organic manures, such as dried poultry manure, rape-dust, or fish-meal. This may be associated with the much higher quantity of potash contained in dung. The effects of curvature and interaction on percentage ware are generally in the same direction as on yield. Curvature is almost always negative, and interaction effects, although small, are rather more frequently positive than negative. There are, however, well-pronounced negative interactions between dung and potash.

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APPENDIX

TABLE I. *Effect of Sulphate of Ammonia*

NO DUNG

No.	Year	Soil	Variety	N cwt. per acre	Riddle-size, in.	Yield, no N, tons	Increase for N, per cent.	Percentage Ware: No nitrogen	Percentage Ware: Increase for N	
1	1931	Heavy loam	A	0·6	*	7·83	6·06	89·7	+0·9	±2·00
2	1932	,, ,,	A	0·6	*	6·34	*22·6*	93·7	−0·6	±0·81
3	1933	,, ,,	A	0·6	1¾	4·16	14·6	64·2	−6·4	±6·20
4	1934	,, ,,	A	0·6	1¾	6·11	18·0	77·3	+5·4	±4·40
5	,,	Loam	GS	0·6	†	7·32	20·0	98·1	−0·7	±0·42
6	,,	Sandy	AC	0·5	*	13·63	*8·4*	82·1	*+7·6*	±2·61
7	,,	Silty gravel	KE	0·6	1½	8·10	*11·9*	64·8	+0·9	±2·72
8	,,	Medium loam	GS	0·6	1½	5·17	*31·1*	89·3	+2·7	±1·50
9	,,	Sandy	GS	0·3	1½	10·36	*13·5*	86·2	−1·7	±2·07
,,	,,	,,		0·6	,,	,,	*18·4*	,,	−2·4	±2·07
10	,,	Clay	KE	0·6	1½	8·25	*14·0*	87·7	+1·0	±0·77
11	,,	Sandy	EC	0·6	1⅝	5·53	*13·8*	64·6	*+5·1*	±1·49
12	,,	Strong Fen	M	0·3	1½	7·56	*16·9*	94·1	−0·8	±0·93
,,	,,	,, ,,		0·6	,,	,,	*32·4*	,,	+0·2	±0·93
13	,,	Light Fen	M	0·3	1½	6·79	10·2	83·9	+3·7	±2·09
,,	,,	,, ,,		0·6	,,	,,	*29·5*	,,	*+6·8*	±2·09
14	,,	Light Fen	M	0·3	1½	8·25	9·3	86·2	−2·0	±1·78
,,	,,	,, ,,		0·6	,,	,,	10·5	,,	−2·4	±1·78
15	,,	Loam	KE	1·0	*	6·11	*43·0*	55·8	*+26·1*	±4·34
16	1935	Light loam	KP	0·6	*	7·08	*17·2*	66·3	*+4·8*	±1·56
17	,,	Medium loam	AB	0·6	†	12·54	*25·9*	79·2	−4·0‡	
18	,,	Silty gravel	M	0·4	*	4·91	*13·9*	85·6	+0·4	±4·02
,,	,,	,,	,,	0·8	,,	,,	*31·9*	,,	+2·0	±4·02
19	,,	Light Fen	KE	0·3	1⅝	8·81	7·7	64·7	−2·8	±3·96
,,	,,	,, ,,	,,	0·6	,,	,,	*13·8*	,,	−6·2	±3·96
20	,,	Strong Fen	M	0·3	1⅝	5·23	*26·6*	79·4	+3·5	±2·01
,,	,,	,, ,,	,,	0·6	,,	,,	*42·7*	,,	*+5·4*	±2·01
21	,,	Light Fen	M	0·5	1⅝	5·58	9·1	63·8	+2·4	±3·18
22	,,	Heavy loam	A	0·6	1¾	5·46	16·4	70·9	+3·5	±3·15
23	1936	Heavy loam	A	0·4	1¾	4·83	19·5	70·7	+2·7	±3·45
24	,,	Light Fen	M	0·3	1½	4·73	*30·3*	73·6	+1·9	±3·38
,,	,,	,, ,,	,,	0·6	,,	,,	*25·5*	,,	+4·0	±3·38
25	,,	Chalky loam	KE	0·6	*	4·71	*40·3*	62·4	+2·3	±3·94
26	,,	Light loam	KP	0·4	1¾	8·68	*8·0*	80·4	*+3·5*	±1·21
,,	,,	,, ,,	,,	0·8	1¾	,,	5·8	,,	+0·9	±1·21
27	,,	Heavy loam	A	0·6	1¾	7·86	12·7	85·5	+0·6	±1·93
28	,,	Sand	A	0·6	1¾	3·95	*59·8*	75·6	+3·9	±3·74
29	,,	Gravel	KE	0·4	1½	2·20	*26·2*	55·7	+4·7	±2·81
,,	,,	,,	,,	0·8	,,	,,	*37·9*	,,	*+7·5*	±2·81
				WITH DUNG						
30	1935	Light fen	M	0·3	1⅝	7·98	12·1	86·2	+1·0	±2·32
,,	,,	,, ,,	,,	0·6	,,	,,	3·0	,,	−2·1	±2·32
31	,,	Light loam	KE	0·3	*	8·64	−3·2	68·1	+0·6	±2·42
,,	,,	,, ,,	,,	0·6	*	,,	−0·4	,,	+3·0	±2·42
32	,,	Light Fen	M	0·5	1⅝	7·74	*17·6*	83·3	−3·2	±3·18
33	1936	Heavy loam	A	0·4	1¾	7·06	3·6	76·4	−1·2	±2·44
34	,,	Strong Fen	M	0·3	1½	2·35	*43·2*	77·8	+0·4	±1·60
,,	,,	,, ,,	,,	0·6	1½	,,	*53·6*	,,	*+3·6*	±1·60

* Not specified. † Hand-sorted. ‡ Bulked replicates.

NOTE.—Figures in italics are statistically significant.

Varieties: A: Ally. GS: Gt. Scot. AC: Arran Chief. KE: King Edward. EC: Eclipse. M: Majestic. KP: Kerr's Pink. AB: Arran Banner.

TABLE II. *Effect of Superphosphate*

NO DUNG

No.	*Year*	*Soil*	*Variety*	*P_2O_5 cwt. per acre*	*Size of riddle, in.*	*Yield, no super., tons*	*Increase for P per cent.*	*Percentage Ware* *No super.*	*Percentage Ware* *Increase for P*	
1	1931	Heavy loam	A	0·6	*	6·52	*20·7*	91·7	−4·1	±2·00
2	1932	,, ,,	A	0·6	*	7·62	9·1	94·3	−0·8	±0·81
3	1933	,, ,,	A	0·6	1¾	3·77	*45·4*	71·1	+4·6	±6·20
4	1934	,, ,,	A	0·6	1¾	5·12	17·3	75·1	+1·6	±4·40
5	,,	Clay	KE	0·5	1½	7·73	*25·8*	88·6	−0·8	±0·77
6	,,	Sandy	EC	0·5	1⅝	5·82	4·0	66·2	+1·8	±1·49
7	,,	Strong Fen	M	0·75	1½	7·00	*27·5*	92·7	+1·9	±0·93
,,	,,	,, ,,	,,	1·50	,,	,,	*40·3*	,,	+1·6	±0·93
8	,,	Light Fen	M	0·75	1½	7·59	1·0	88·2	−0·9	±2·09
,,	,,	,, ,,	,,	1·50	,,	,,	8·4	,,	−1·4	±2·09
9	,,	Light Fen	M	0·75	1½	6·99	*30·3*	86·7	−1·5	±1·78
,,	,,	,, ,,	,,	1·50	,,	,,	*32·1*	,,	*−4·4*	±1·78
10	,,	Loam	KE	1·28	*	7·77	*21·2*	77·0	+4·8	±4·34
11	1935	Heavy loam	A	0·6	1¾	6·43	0·6	80·1	−2·6	±3·15
12	,,	Light Fen	KE	0·75	1⅝	8·91	7·0	59·4	+3·5	±3·96
,,	,,	,, ,,	,,	1·50	,,	,,	11·4	,,	+3·3	±3·96
13	,,	Strong Fen	M	0·75	1⅝	6·15	11·5	82·4	−0·8	±2·01
,,	,,	,, ,,	,,	1·50	,,	,,	*17·2*	,,	+0·7	±2·01
14	,,	Light Fen	M	1·0	1⅝	5·66	6·9	62·8	+4·5	±3·18
15	,,	Heavy	AB	0·8	†	3·63	*31·7*	63·3	+18·3	±4·81
,,	,,	,, ,,	,,	,, ‡	,,	,,	−7·1	,,	+7·5	±4·81
16	1936	Light Fen	M	0·75	1½	4·73	*26·5*	74·0	+3·6	±3·38
,,	,,	,, ,,	,,	1·50	,,	,,	*29·4*	,,	+1·0	±3·38
17	,,	Gravel	KE	0·4	1½	2·05	*39·6*	54·8	*+6·5*	±2·81
,,	,,	,,	,,	0·8	,,	,,	*40·4*	,,	*+8·5*	±2·81
18	,,	Chalky loam	KE	0·8	*	5·56	*11·2*	62·3	+2·6	±3·94
19	,,	Heavy loam	A	0·6	1¾	7·61	20·9	86·2	−0·4	±1·93
20	,,	Sandy	A	0·6	1¾	8·00	−16·4	81·9	−6·8	±3·74
						WITH DUNG				
21	1935	Light Fen	M	0·75	1⅝	8·05	1·3	83·8	+1·8	±2·32
,,	,,	,, ,,	,,	1·50	,,	,,	11·3	,,	+4·3	±2·32
22	,,	Light Fen	M	1·0	1⅝	8·15	6·3	79·4	+4·5	±3·18
23	1936	Heavy Fen	M	0·75	1½	2·50	*+23·4*	77·8	+1·5	±1·60
,,	,,	,, ,,	,,	1·50	,,	,,	*+60·4*	,,	+2·4	±1·60

* Not specified. † Hand-sorted. ‡ Basic Slag.

TABLE III. *Effect of Potash*

NO DUNG

No.	Year	Soil	Variety	K_2O cwt. per acre	Size of riddle, in.	Yield, no K, tons	Increase for K, per cent.	Percentage Ware: No potash	Percentage Ware: Increase for K	
1	1931	Heavy loam	A	1·0	*	4·33	55·4	78·2	+14·3	±2.00
2	1932	,, ,,	,,	1·0	*	6·41	25·0	93·4	+0·6	±0·81
3	1933	,, ,,	A	1·0	1¾	2·93	31·4	47·0	+18·4	±6·20
4	1934	,, ,,	A	1·0	1¾	3·08	64·0	61·4	+18·8	±4·30
5	,,	Strong Fen	M	0·75	1½	8·80	−0·4	93·7	+0·1	±0·93
,,	,,	,, ,,	,,	1·50	,,	,,	8·7	,,	+0·5	±0·93
6	,,	Light Fen	M	0·75	1½	6·79	17·1	83·3	+5·6	±2·09
,,	,,	,, ,,	,,	1·50	,,	,,	23·0	,,	+6·7	±2·09
7	,,	Light Fen	M	0·75	1½	6·04	39·0	76·8	+10·5	±1·78
,,	,,	,, ,,	,,	1·50	,,	,,	54·7	,,	+13·4	±1·78
8	,,	Loam	KE	1·50†	*	7·12	29·7	72·4	+9·4	±4·43
9	1935	Heavy loam	A	1·0	1¾	6·57	16·0	69·9	+7·8	±3·15
10	,,	Light Fen	KE	0·75	1⅝	7·16	27·4	49·5	+14·3	±3·96
,,	,,	,, ,,	,,	1·50	,,	,,	45·4	,,	+22·2	±3·96
11	,,	Strong Fen	M	0·75	1⅝	6·71	6·9	83·0	−0·8	±2·01
,,	,,	,, ,,	,,	1·50	,,	,,	−2·9	,,	−1·1	±2·01
12	,,	Light Fen	M	1·25	1⅝	4·69	34·0	53·9	+22·2	±3.18
13	1936	Light Fen	M	0·75	1½	4·15	47·3	68·9	+8·3	±3·38
,,	,,	,, ,,	,,	1·50	,,	,,	38·5	,,	+11·7	±3·38
14	,,	Gravel	KE	0·8	1½	2·55	21·4	62·1	+0·3	±2·81
,,	,,	,, ,,	,,	1·6	,,	,,	5·0	,,	−7·3	±2·81
15	1936	Chalky loam	KE	1·0†	*	5·41	16·5	59·0	+9·3	±3·94
16	,,	Heavy loam	A	1·0	1¾	7·34	5·9	81·0	+6·2	±1·93
17	,,	Sandy	A	1·0	1¾	7·54	18·3	78·9	+5·9	±3·74
				WITH DUNG						
18	1935	Light Fen	M	0·75	1⅝	7·86	7·6	87·2	−2·2	±2·32
,,	,,	,, ,,	,,	1·50	,,	,,	10·8	,,	−2·0	±2·32
19	1935	Light Fen	M	1·25	1⅝	8·39	−0·4	83·6	−3·9	±3·18
20	,,	Light loam	KE	0·75	*	8·60	−4·2	67·1	+3·0	±2·42
,,	,,	,, ,,	,,	1·50	,,	,,	+2·2	,,	+3·6	±2·42
21	,,	Warp	M	0·5	*	9·14	13·2	86·7	+2·9	±0·88
,,	,,	,, ,,	,,	1·0	,,	,,	17·2	,,	+1·7	±0·88
,,	,,	,, ,,	,,	1·5	,,	,,	26·2	,,	+2·9	±0·88
22	1936	Heavy Fen	M	0·75	1½	3·21	12·7	78·5	+1·3	±1·60
,,	,,	,, ,,	,,	1·50	,,	,,	9·5	,,	+0·5	±1·60

* Not specified. † Muriate of potash.

TABLE IV. *Effect of Dung*

No.	Year	Soil	Variety	Dung, tons	Size of riddle, in.	Yield, no dung, tons	Increase for dung, per cent.	Percentage Ware: No dung	Percentage Ware: Increase for dung		Basal dressing
1	1935	Clay loam	A	15	1¾	3·90	33·3	52·0	+22·1	±1·87	Nil
,,	,,	,,	,,	,,	,,	5·56	22·5	65·6	+9·5	±1·87	PK
,,	,,	,,	,,	,,	,,	3·38	66·0	44·1	+34·2	±1·87	N
,,	,,	,,	,,	,,	,,	8·13	15·0	74·0	+5·3	±1·87	NPK
2	1935	Light Fen	M	8½	1⅝	5·58	30·3	63·8	+19·5	±3·18	No N
,,	,,	,,	,,	,,	,,	6·23	38·8	66·2	+13·8	±3·18	N
,,	,,	,,	,,	,,	,,	5·66	34·8	62·8	+16·6	±3·18	No P
,,	,,	,,	,,	,,	,,	6·15	34·3	67·2	+16·6	±3·18	P
,,	,,	,,	,,	,,	,,	4·69	51·8	53·9	+29·7	±3·18	No K
,,	,,	,,	,,	,,	,,	7·12	17·3	76·1	+3·6	±3·18	K
3	1936	Clay loam	A	15	1¾	4·83	46·1	70·7	+7·7	±3·45	PK
,,	,,	,,	,,	,,	,,	6·13	29·4	73·4	+5·4	±3·45	NPK

TABLE V. *Effect of Organic Nitrogen*

NO DUNG

No.	Year	Soil	Variety	N cwt. per acre	Size of riddle, in.	Yield, no N, tons	Increase for N, per cent.	Percentage Ware: No nitrogen	Percentage Ware: Increase for nitrogen	
DRIED POULTRY MANURE										
1	1934	Loam	GS	0·6	†	7·32	1·7	98·1	−0·3	±0·42
2	,,	Sandy	AC	0·5	*	13·63	3·9	82·1	+1·4	±2·61
3	,,	Silty gravel	KE	0·6	1½	8·10	12·4	64·8	+1·4	±2·72
4	,,	Medium loan	GS	0·6	1½	5·17	24·4	89·3	−1·4	±1·50
5	,,	Sandy	GS	0·3	1½	10·36	9·1	86·2	−1·2	±2·07
,,	,,	,,	,,	0·6	,,	,,	11·7	,,	−1·5	±2·07
6	,,	Clay	KE	0·6	1½	8·48	8·8	88·3	−0·1	±0·77
7	,,	Sandy	EC	0·6	1⅝	5·29	21·9	64·4	+5·3	±1·49
8	1935	Light loam	KP	0·6	*	7·08	10·3	66·3	+5·1	+1·56
9	,,	Medium loam	AB	0·6	†	12·54	9·7	79·2	−1·0‡	
10	,,	Silty gravel	M	0·4	*	4·91	6·9	85·6	−0·4	±4·02
,,	,,	,, ,,	,,	0·8	*	,,	20·1	,,	+0·6	±4·02
11	1936	Light loam	KP	0·4	1¾	8·68	−0·4	80·4	+5·6	±1·21
,,	,,	,, ,,	,,	0·8	,,	,,	10·1	,,	+1·2	±1·21
MALT CULMS										
12	1934	Silty gravel	KE	0·6	1½	8·10	4·0	64·8	−3·3	±2·72
13	1935	Light loam	KP	0·6	*	7·08	10·5	66·3	+5·5	±1·56
FISH-MEAL										
14	1934	Sandy	AC	0·5	*	13·63	3·6	82·1	−1·8	±2·61
RAPE-CAKE										
15	1934	Medium loam	GS	0·6	1½	5·17	35·4	89·3	+3·0	±1·50

* Not specified. † Hand-sorted. ‡ Bulked replicates.

TABLE VI. *Effect of Complete Artificials (NPK)*

NO DUNG

No.	Year	Soil	Variety	Fertilizer, cwt.	Riddle, in.	Yield, no fertilizer, tons	Increase for fertilizer, per cent.	Percentage Ware: No fertilizer	Percentage Ware: Increase for fertilizer	
1	1935	Clay loam	A	12	$1\frac{3}{4}$	3·90	74·7	52·0	+22·4	±2·37
2	1936	Limestone	KE	4	$1\frac{1}{2}$	3·62	21·7	75·8	+1·9	±1·60
,,	,,	,,	,,	8	,,	,,	39·6	,,	+5·0	±1·60
,,	,,	,,	,,	12	,,	,,	51·8	,,	+7·4	±1·60
,,	,,	,,	,,	16	,,	,,	41·7	,,	+6·1	±1·60
3	,,	Limestone	KE	4	$1\frac{1}{2}$	4·93	16·2	62·7	−0·4	±1·04
,,	,,	,,	,,	8	,,	,,	25·8	,,	+2·6	±1·04
,,	,,	,,	,,	12	,,	,,	23·5	,,	+2·0	±1·04
,,	,,	,,	,,	16	,,	,,	26·6	,,	+1·5	±1·04

WITH DUNG

No.	Year	Soil	Variety	Fertilizer, cwt.	Riddle, in.	Yield, no fertilizer, tons	Increase for fertilizer, per cent.	Percentage Ware: No fertilizer	Percentage Ware: Increase for fertilizer	
4	1935	Clay loam	A	12	$1\frac{3}{4}$	6·18	61·9	74·1	+7·1	±1·68
5	,,	Light loam	KE	4	*	7·83	2·4	76·6	−0·4	±6·48
,,	,,	,, ,,	,,	8	,,	,,	−1·4	,,	−3·5	±6·48
,,	,,	,, ,,	,,	12	,,	,,	−0·5	,,	−2·0	±6·48
6	,,	Sand	M	4	$1\frac{5}{8}$	5·26	20·0	72·5	+4·1	±2·74
,,	,,	,,	,,	8	,,	,,	42·6	,,	+5·1	±2·74
,,	,,	,,	,,	12	,,	,,	55·5	,,	+6·2	±2·74
,,	,,	,,	,,	16	,,	,,	56·3	,,	+3·8	±2·74
7	1936	Light loam	KP	4	$1\frac{1}{2}$	10·71	1·2	75·1	+4·8	±3·56
,,	,,	,, ,,	,,	8	,,	,,	−2·4	,,	+4·3	±3·56
,,	,,	,, ,,	,,	12	,,	,,	−9·0	,,	+0·8	±3·56

* Not specified.

THE REACTION OF DIFFERENT GRADES OF LIMESTONE WITH AN ACID SOIL

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NUMEROUS investigators have studied the comparative effect of various liming materials as soil amendments. It appears to be generally agreed that equivalent amounts of calcium as quicklime, hydrated lime, and finely ground limestone can be regarded as equally effective. There is, however, considerable diversity of opinion concerning the relative effectiveness of ground limestone of varying degrees of fineness. That which passes through a sieve with 100 meshes to the linear inch is generally acknowledged to be as efficient as any other form of lime, but, whilst some workers believe that material which does not pass through a 60- or 80-mesh sieve is too slowly reactive to be of much value in correcting soil acidity, others have recommended the use of limestone which has been ground so that all passes through the 10-mesh sieve. The latter investigators believe that this material contains enough fine material to have immediate value, and that the coarse material becomes available with time. Several reasons may be put forward to account for this conflict of opinion. Probably the main reason is that due regard has not been paid to the time factor.

Lyon [1] found that the beneficial effects, shown by increased yield, of the 200-mesh material were greater when first applied but passed more rapidly than those of the 50–80 mesh. Only the fraction 5–10 mesh failed to give any response. A good review of the literature up to 1930 with a large number of references has been given by Pierre [2]. His work and that of others, such as Walker and Brown [3], show clearly that, as might be expected, the rate of reaction of coarsely ground limestone with soils is much slower than that of the finely ground material. Walker and Brown showed that the mean differences for a 5-year period between the pH of soils treated with 40- and 100-mesh limestone were not significant, and that the 40-mesh limestone was nearly as effective as the 100-mesh during the first year. Pierre also found that all liming materials reacted more rapidly with very acid soils. Thus the time factor varies in its significance with the degree of acidity of the soil. It seems highly probable, therefore, that the chief reason for the comparative failures of coarsely ground limestone when measured in terms of plant-growth response—and this is the ultimate test—is that a sufficient period of time has not been allowed for reaction between the limestone and soil before testing with crops. Finely ground material reacts rapidly and, therefore, gives a response within a few months. The experiment should be carried out over a number of years if a true measure of the effect of the two grades of limestone is to be obtained.

Almost all experimental work of this kind has been done in America.

In Wales, the only work known to the writer is that by Griffith [4], who reports the results of pot experiments on the effect of limestone separates on the growth of trefoil. He found that material finer than 100-mesh was effective in causing increased growth and that coarser separates were without appreciable effect. Two reasons might be put forward to account for this almost complete failure of the coarse separates: (1) the duration of the experiment was about six months. This is too short a period for the coarser materials to react with the soil to any great extent. (2) The soil appears to have been extremely acid and deficient in lime. It is probable that the dressing (0·3 per cent. $CaCO_3$) was too small to be really effective until the bulk of it had reacted with the soil. It is, therefore, possible that if the experiment had been repeated on the same soil after allowing a period of one or two years for reaction to take place, more favourable results would have been obtained with the coarser separates. If coarsely ground material can be effective in two or three years it is of considerable value as a dressing, as it is neither economical nor practical to apply small frequent dressings of liming materials. The effect of lime is expected to last over the period of rotation and longer. In Wales the average rotation covers a period of 8 to 10 years, of which 3 years are under arable. It is possible, therefore, that before the end of the rotation period, a dressing of the coarser material may have produced its full effect. In view of the lack of decisive evidence on the behaviour of coarsely ground limestone under Welsh conditions, and of the conflict of opinion elsewhere, and also in view of the fact that the present practice of grinding limestone so that nearly all passes through the 100-mesh sieve renders the application of ground limestone uneconomical when compared with the cost of lump lime, it was decided to lay down a simple experiment in an attempt to obtain some further information on the question.

The main reason for the addition of liming materials to soils is to increase the available calcium and to reduce soil acidity. Once they have reacted with the soil and their calcium has entered the soil colloidal complex this calcium becomes indistinguishable from that which was already present in exchangeable form. It is, therefore, possible to assess the reactivity of such liming materials by chemical methods. Those which have been more commonly employed are: (1) measurement of the changes in the pH of the soil; (2) measurement of the reduction in the exchangeable hydrogen by one or other of the conventional lime-requirement methods; or (3) determination of the residual carbonate after allowing the liming material to react with the soil for a definite period of time. It seems to the writer that a more complete picture of what has taken place could be obtained by measuring the change in exchangeable calcium. If a definite amount of calcium carbonate has been applied to the soil, and if after the period allowed for reaction the residual carbonate and exchangeable calcium are determined, it will then be possible to calculate how much has been removed through drainage and cropping, and how much of the added material has reacted with the soil and become fixed in the colloidal complex. The writer has attempted to do this in the experiment described below.

Experimental

A quantity of fairly acid soil of medium texture and good organic-matter status from land under old pasture (Table 1) was air-dried and the stones separated by passing through a 2 mm. sieve. Kilogramme lots of the soil were weighed out and carefully mixed with 0·5 per cent. of separates from:

(*a*) A commercial ground limestone of high purity.
(*b*) Marble which had been ground up in the laboratory.
(*c*) Precipitated calcium carbonate of A.R. quality.

TABLE 1. *Analytical Data for Soil Used*

Mechanical Analysis (Dry at 105° C.)		*Chemical Data*	
Coarse sand	23·0 %	Loss on ignition	13·6 %
Fine sand	21·5 %	Organic carbon	5·4 %
Silt	17·0 %	Org. matter (C × 1·724)	9·3 %
Clay	26·1 %	Exchangeable CaO (5·89 M.E.)	0·165 %
Moisture	4·5 %	HCl-soluble CaO (8·71 M.E.)	0·244 %
Loss by H_2O_2-treatment, &c.	7·9 %	pH	4·85

The range of particle-size in the various separates is shown in Table 2. After mixing, the soils were packed into pots and placed out of doors, where they were allowed to remain for a period of 2½ years, including three winters. At the end of this period the pots were brought indoors, the soil air-dried, and again passed through the 2 mm. sieve so as to

TABLE 2. *Influence of Limestone Separates on the Exchangeable Calcium and pH of an Acid Soil after a Period of 2½ Years, following a Dressing of 10 M.E. (0·5 per cent.) $CaCO_3$*

	Milligramme Equivalents (M.E.) per 100 gm. of Soil				
Description of separates	*Residual carbonate*	*Exchangeable calcium*	*Increase in exchangeable calcium over that of original soil*	*Net loss of calcium (drainage)*	*pH*
Marble					
2 mm.–20 mesh	1·96	11·30	5·41	2·04	5·60
20 mesh–40 mesh	0·50	12·92	7·03	2·46	5·56
40 mesh–60 mesh	0·46	13·07	7·18	2·36	5·53
60 mesh–90 mesh	0·64	12·73	6·84	2·59	5·67
Finer than 90	0·75	12·24	6·35	2·89	5·67
Commercial Limestone					
2 mm.–20 mesh	0·89	12·50	6·61	2·50	5·67
20 mesh–40 mesh	1·57	13·07	7·18	1·25	5·72
40 mesh–60 mesh	0·36	12·83	6·94	2·68	5·51
60 mesh–90 mesh	0·53	11·62	5·73	3·71	5·55
Finer than 90	0·82	12·35	6·46	2·71	5·58
Pure $CaCO_3$	0·53	12·20	6·31	3·14	5·55

break up lumps. The residual carbonate and exchangeable calcium were then determined on all samples. The method used was that described by the writer [5] and consists essentially in estimating the residual carbonate and the exchangeable calcium on the same sample by treatment with 0·5 N acetic acid. In this way sampling errors which may be considerable when carbonate is present in coarse form are greatly reduced. In carrying out the determination 25 gm. lots of soil were used, and 1,000 c.c. of 'leachate' were collected in the first instance, followed by a further 500 c.c. The amount of calcium in the last 500 c.c. was small and in most cases negligible. All estimations were done in duplicate and some in triplicate. Whilst in the case of the soil treated with a few of the coarser separates, some variation was found in the figures for the duplicates of the residual carbonate, the figures for the exchangeable calcium of the same duplicates showed close agreement. The mean figures are shown in Table 2 and are all expressed in terms of milligramme equivalents per 100 gm. soil.[1] Where the amount of $CaCO_3$ is greater than 1 M.E. the figure given is the mean of several replicate determinations.

The results in Table 2 show that, under the conditions of the experiment, the reaction between the various materials and the soil is almost complete after 2½ years. On the basis of residual carbonate alone, over 80 per cent. has disappeared in all cases. It has not completely gone in any of the samples, but only in two is it greater than 1 M.E. per 100 gm. of soil. The reason why all the soils contain a small amount of carbonate is partly the fact that small amounts of carbonate were formed during drying from the bicarbonate present in the soil solution when the pots were removed indoors, and partly the difficulty of determining accurately small amounts of carbonate in soils containing appreciable amounts of organic matter, owing to the tendency of easily hydrolysable organic matter to decompose on treatment with acid. In carrying out replicate estimations, using either dilute phosphoric or dilute hydrochloric acid, of the carbonate in the soils with the higher residual carbonate, it was observed that a slow continuous evolution of carbon dioxide took place, indicating decomposition of organic matter. However, on the addition of a reducing agent ($SnCl_2$ solution) this was prevented and close agreement between replicates was obtained. The figures in the table were obtained by this method. Column 3 shows the figures for the exchangeable calcium of the treated soils. The variation in the values of the extremes is only 1·77 M.E. and is not regular in any direction with either the marble or the commercial separates. Therefore, the variation is probably due to experimental errors and also to the influence on drainage of differences in the packing of the soil in the pots. The figures indicate that all the separates have reacted similarly with this particular soil. It is possible that a number of replicates of each treatment might have provided data for a closer differentiation. A similar irregularity and lack of significant differentiation is observed in the figures of columns 4 and 5, viz. increase in exchangeable calcium over that of the original soil and net loss of calcium. The latter figures

[1] 1 milligramme equivalent (M.E.) = 0·028 g. CaO.

were obtained by subtracting the exchangeable calcium plus the calcium of the residual carbonate from the original exchangeable calcium plus the added calcium. As no crop was grown in the pots, this difference is accounted for by, and represents, the loss through drainage. It is unlikely, and there is no evidence to indicate, that any of the added calcium can have reverted to a non-exchangeable form. Support for this view is found in figures which were obtained for the total HCl-soluble calcium of the original soil and the soil treated with pure calcium carbonate. The difference between them was found to be 6·6 M.E. This is slightly less than the residual carbonate plus the increase in exchangeable calcium, viz. 6·8 M.E. Thus the figures in column 5 indicate fairly closely the amount lost in drainage. They are naturally fairly high under the conditions of free drainage and loose artificial packing. On theoretical grounds it is probable that the carbonate is more readily leached out than the exchangeable calcium, and the finer grades of carbonate more readily than the coarser. With the finer separates the loss would be higher in the initial stages, before reaction has taken place, whilst for the coarser separates, owing to the slower reaction, it would be more evenly spread over the whole period. Column 6 shows the pH of the treated soils. Here again a fairly close agreement and a random variation are shown. It is therefore concluded that the data obtained in this experiment show that the various limestone separates will react to a similar extent in a reasonable period of time, provided they are intimately mixed with an acid soil and given optimum conditions for the reaction. Such optimum conditions would be obtained in the mild humid climate of Wales with a well-distributed rainfall and free drainage. The soil used was admittedly of a fairly acid character and of a large buffer capacity, but was not unrepresentative of a type of soil common in many parts of Wales. The dressing given was a fairly high one, corresponding to 5 tons per acre of ground limestone, but on this soil it is probable that such a dressing would have been needed to raise its lime-status to a fairly satisfactory level. Calculations from the mean figures in columns 4 and 6 of Table 2 show that to change the pH by 1 unit requires an increase of 8·8 M.E. of calcium, i.e. 0·44 per cent. of calcium carbonate. The final lime-status is probably quite satisfactory for the type of farming practised on these soils. A dressing of ground limestone finer than 20-mesh may thus be expected to furnish enough fine material for immediate use and a reserve for reaction in subsequent years.

General Conclusions

The results discussed above support the views of the American workers who recommend the use of relatively coarsely ground limestone. As previously mentioned, they believe that if it has been ground to pass through a 10-mesh sieve it will contain sufficient fine material to be immediately effective, whilst the coarser material becomes available with time. Although under field conditions it would not be possible to ensure such intimate mixing as can be obtained in pot experiments yet, as it is not practical to apply lime dressings except at intervals of several

years, it would all be expected to have reacted before the time comes for the next application. The complete neutralization of soil acidity is not considered essential for most of the crops commonly grown in Wales. In fact, an appreciable amount of acidity may be tolerated without deleterious effect. It is, however, essential to have a substantial reserve of available calcium present. The amounts necessary for Welsh conditions have been discussed elsewhere [6]. When the lime-status of the average Welsh soil has been raised to a satisfactory level, the soil will still have a considerable reserve of acidity when measured in terms of the amount of lime required to raise its reaction to neutrality. Under such conditions the writer believes that the coarser material would all react with the soil in the period of a few years, and if the limestone was ground so that all, or nearly all, passed the 20-mesh sieve, a sufficiency of the finer grades to produce an immediate effect would be ensured.

It might be asked whether the coarser material would be effective on grassland. In practice, it is always preferable to apply liming materials during the arable part of the rotation. This ensures a more thorough incorporation in the soil, and therefore a more rapid reaction than would follow with a surface-application to grassland. The writer has no evidence as to the penetration of coarsely ground limestone into the soil when applied as a surface-dressing. It is obvious that fineness of grinding is a factor of great importance, but on very acid soils under grass it is probable that the coarser material (<20 mesh) might be used with advantage.

Ground Limestone v. *Lime*

At the present time very little ground limestone is used in Wales. In comparison with the actual deficiency little lime of any kind is used, but of this only a small percentage is ground limestone. The reasons for this preference for other forms of lime are mainly economic; burnt lime is cheaper per unit of weight of calcium than ground limestone. It has been the custom to reduce the limestone to such a fine powder that about 80 per cent. of it will pass through a 100-mesh sieve. It is obvious that if a coarser type of material were used it could be produced more cheaply, and it might eventually replace burnt lime as a soil dressing. The final effect of both on the soil is the same, so that the question reduces itself to that of economics and convenience. Both materials are subject to certain advantages and disadvantages. Burnt lime for agricultural purposes is usually produced in three forms: (1) lump lime, (2) ground lime, or (3) hydrated lime. Preference is generally given to lump lime on account of its relative cheapness. The writer considers that often this is false economy, for it has to be slaked to a fine powder before spreading over the land. Unless great care is taken with the slaking a part of it may cake into small or even large lumps, which will take a very long time to react with the soil. Such lumps have been found in acid soils which have not been limed for many years. Even if the slaking is satisfactorily carried out it is difficult to spread the lime evenly over the surface of the soil. Ground lime is not subject to the same disadvantages as lump lime, but it is somewhat

dearer and is unpleasant to handle owing to its caustic action. This material cannot be stored for any length of time as it absorbs moisture with resultant swelling out and bursting of the bags. Hydrated lime is not subject to this drawback, but it is too expensive to use for general soil purposes. Ground limestone does not suffer from the same disadvantages on storage. It can be kept indefinitely in a relatively dry place without caking or deterioration, and can be applied broadcast or with a drill without any danger of unpleasant effects to the workmen during handling. From the farmer's point of view the disadvantage of ground limestone is the initial cost, cartage, and labour in applying approximately twice the weight of an equivalent amount of quicklime. On the other hand, if by producing a coarser type of material the final cost, including its application on the land, can be reduced so as to be on a par with that of lump lime, the advantage of being able to obtain a product which can be stored and handled without any deterioration or deleterious effect would outweigh any other considerations and prejudices against its use. It is probable, in view of the present agricultural policy in Great Britain, that there will be a much increased demand for liming materials. This will come at certain peak periods in the autumn and the spring and it seems likely that the manufacturers will find it difficult to execute their orders for burnt lime during these periods because it cannot be kept in stock and has to be burnt as demand arises. On the other hand, the manufacturer would find it possible to prepare large quantities of ground limestone to keep in stock ready for immediate delivery during peak periods. Such a policy would be of advantage both to the manufacturer and to the farmer.

Summary

Ground limestone and marble separates of grades varying from 2 mm. to finer than 90 mesh were mixed with an acid soil and kept out of doors for 2½ years. Data for residual carbonate, exchangeable calcium, and pH showed that in all cases over 80 per cent. of the carbonate had reacted with the soil by the end of this period.

These data suggest that the use of a coarser grade of ground limestone, say, finer than 20 mesh, would be as effective as the finer grades now commonly used in Great Britain. Since the finer grades are more expensive to produce there would be an economy in using the coarser grades. It is probable that the wastage by drainage might be less.

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THE MILK CONSUMPTION AND GROWTH OF SUCKLING PIGS

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THE lightest pigs at, or before, weaning are by no means always the 'poorest doers' in later life. This fact has been indirectly indicated by many who have worked with the correlations between weights at various ages, and the principle receives practical recognition in the grouping of growing pigs according to size rather than age.

The explanation generally accepted is that there are differences between the quantities of milk produced by sows and between the amounts of milk obtained by individual pigs of a litter. Concerning the differences between sows there can be little doubt [1, 2], but for the differences between the quantities of milk obtained by the pigs of a litter the evidence is mainly indirect. During the progress of research work with a Large White herd in Edinburgh, an effort is being made to isolate genetic differences in the growth-rate of pigs from conception to weaning, and for this purpose it has seemed desirable to obtain some direct evidence on the quantities of milk obtained by suckling pigs. In this way it was hoped to determine whether variations in growth-rate could be completely explained by varying levels in food-supply. In contrast to previous investigations of the milk-production of sows, the work here described involved the weighing of individual pigs before and after suckling instead of litter-weighings. For the immediate purposes of the main investigation it is felt that this particular series of observations has been continued long enough, for although some of the outstanding questions have not yet received an answer, progress must be made in other directions before this can be pursued further.

I. THE METHOD

The method adopted was to remove the pigs from the sow 1½–2 hours before the first weighing and thereafter return them to her for suckling only at 2-hour intervals. The greatest difficulty was found to be the tendency of the pigs to urinate after they had suckled, or even to stop suckling to do so, but this was overcome by turning them out of their bedding and making them stand for some minutes in the dunged area of the pen before weighing. Those which had not urinated could be detected by their almost unchanged weight, and were watched. The error arising from this source is considered negligible. The amount of weight lost by urination varied with the size of the pig from about 10–30 gm. Defaecation caused a very slight loss, usually less than 5 gm. After standing the pigs were weighed to the nearest gram. The technique for obtaining the best weight appears to be to use a direct-reading balance (not a spring one), damp the movement down somewhat, and be prepared to read off the weight quickly. The pigs were then

delivered together to the sow. Suckling took place promptly and the pigs were removed as soon as their behaviour showed that the udder was empty. During suckling, the position of each pig on the udder was noted at intervals by means of a system of easily recognized black dots painted on the pigs. The pigs were then weighed again as quickly as possible.

TABLE 1. *Samples of Results obtained by Weighing before and after Suckling (from periods of continuous observation)*

Difference in grams before and after suckling

Pig No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Litter 1 .	2	37	−10	34	29	28	23	9	19	..	32	34	1
	−1	39	26	49	35	38	−4	23	29	27	36	32	−1
	10	40	21	23	38	38	15	41	29	28	31	45	−1
	7	40	25	46	30	38	31	32	27	−2	29	40	28
	15	31	1	20	34	−10	..	32	−9	−11	−1	35	13
	34	187	73	172	166	142	69	137	104	55	128	186	42
Litter 2 .	47	30	7	20	29	25	5	4	35	5	21	49	
	57	36	64	20	36	32	..	7	2	55	..	..	
	22	19	65	29	8	31	..	45	80	10	23	..	
	4	39	30	31	25	15	38	50	..	18	15	36	
	55	13	55	1	9	73	3	22	67	40	55	23	
	60	36	14	24	35	40	..	27	35	2	16	17	
	245	173	235	125	142	216	46	155	219	130	130	125	
Litter 3 .	60	55	100	49	35	73	54	67	52	36			
	83	56	85	58	30	66	71	83	35	36			
	73	43	70	54	27	67	74	72	37	34			
	84	58	90	69	34	66	81	88	47	42			
	67	43	82	61	34	83	77	82	42	41			
	85	61	89	67	35	82	78	78	49	32			
	452	316	516	358	195	437	435	470	262	221			

Litters 1 and 2 were in the first group of experiments, Litter 3 in the second.

The first suckling was often unsatisfactory because both sow and litter were disturbed by the unusual treatment. The rate of adjustment on both sides, however, was remarkably rapid, and whenever continuous observations could be taken the results were surprisingly good provided there was no disturbing feature, such as ailing pigs. The small pigs showed marked differences in their reaction to the necessary handling. The records in Table 1 show that Nos. 1 and 13 in the first lot, and 7 and 8 in the second lot did not obtain their share of milk during the first few sucklings, but whereas the reason was probably severe competition with the first two, which were the lightest in the litter, this would not apply to the second two, which were the second and third heaviest. Large pigs were often found to take no interest in the proceedings until time brought on a sufficient hunger to overcome whatever disinclination to suckle existed. 'No change' in weight was often recorded. An increase or decrease of one or two grams was accounted for by the error in weighing, and is considered as evidence that no milk was obtained. Occasionally, of course, the amount of milk obtained would be offset more or less by the weight loss by urination. The usual causes of no change are, however,

failure by the pigs to suckle promptly and vigorously, and fighting over the possession of a teat. Owing to the very short time during which the milk is liberated by the sow, a pig has to be ready and willing, otherwise the opportunity will be missed.

II. RESULTS

The experiments may be divided into two groups. The first involved observations made only during the day, the pigs being returned to the sow during the night; the second consisted of continuous observations on two sows for a week. The former will be dealt with briefly, as the results obtained were essentially the same as those from the second group, which was the more satisfactory as it gave a complete record.

The type of results found when only daytime records were made is exemplified in Table 2. It will be observed that in spite of the incompleteness of the records, there is a considerable degree of similarity between the amount of milk obtained and the weight and gains of the pigs. All deductions from this table are subject to the proviso that the amounts of milk obtained during the periods of non-observation were of the same proportions as those obtained under observation. The table, with this proviso, does suggest that the large pigs get more milk than the small, that the rate of gain is closely associated with the amount of milk obtained, and that there may be differences in the efficiency $\left(\frac{\text{Increase in wt.}}{\text{Amount of milk}}\right)$ with which the pigs deal with their food-supply.

TABLE 2. *Comparison of Weight of Milk, Weight of Pigs, and Increase in Weight during Period of 29 Sets of Weighings*

(The columns headed 'order' classify the data in the preceding columns in order of magnitude)

Amount of milk gm.	*Order*	*Wt. at start of weighing kg.*	*Order*	*Wt. at end of weighing kg.*	*Order*	*Increase in wt. kg.*	*Order*	*Ratio: inc. in wt. to amt. of milk*
1,143	1	1·737	6 =	2·844	4	1·107	4	0·97
1,080	2	1·747	4	3·114	2 =	1·367	2	1·27
1,027	3	1·822	2	3·260	1	1·438	1	1·40
1,002	4	1·776	3	3·114	2 =	1·338	3	1·34
913	5	1·586	8	2·539	6	0·953	5	1·04
885	6	1·868	1	2·692	5	0·824	6	0·93
825	7	1·737	6 =	2·493	7	0·756	8	0·92
793	8	1·325	10	2·095	9	0·770	7	0·97
747	9	1·740	5	2·401	8	0·661	9	0·88
697	10	1·296	11	1·950	10	0·654	10	0·94
439	11	1·442	9	1·928	11	0·486	11	1·11

In order to determine these points with more certainty, it was decided to carry out complete observations over a period. Two sows with 3-week-old litters were chosen. The sows were even-tempered and soon became used to the treatment. One was raising her third litter and the other was a gilt which had already been observed intermittently. Suckling took place at intervals of approximately two hours during the day, and 3 hours during the night. A sample of the results is given in Table 1 (litter 3) which shows clearly that there is much similarity in

the consecutive amounts of milk obtained, some pigs receiving always a large amount and others a small amount. Two small pigs in the gilt's litter were in the process of losing the struggle for existence, falling in weight owing to repeated failure to secure a teat, and becoming less and less able to assert themselves. One pig of the other litter, No. 4, had an injured front hoof and was handicapped to some extent by that, although it succeeded in retaining its own teat throughout.

The relation between the weight of the pigs, the increase in weight, and the amount of milk obtained (together with two estimates of efficiency) are given in Table 3.

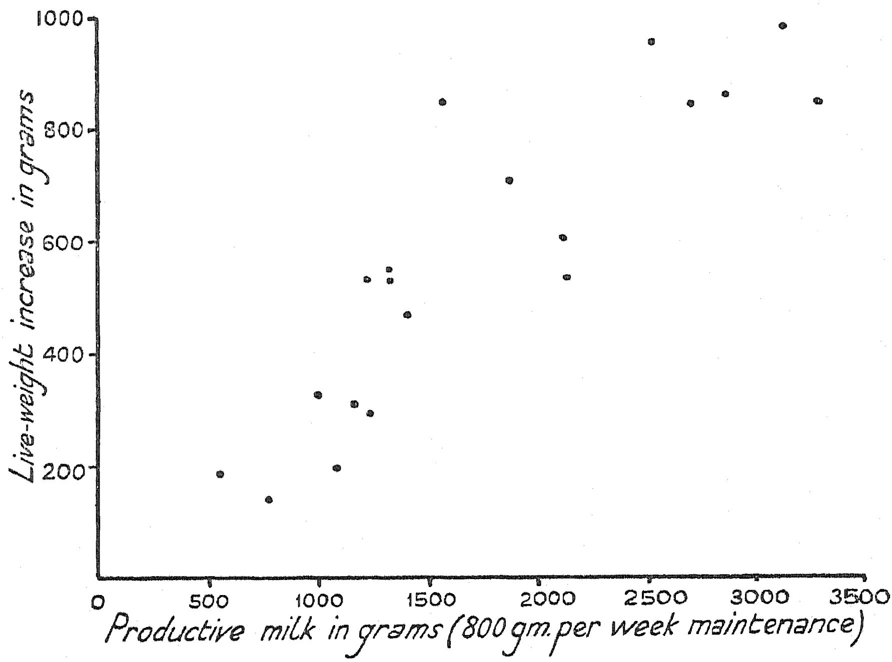
TABLE 3. *Relation between Weight of Pig at Start of Experiment, Increase in Weight, and the Amount of Milk obtained (based on 74 observations during 7 days)*

No.	*Sex*	*Weight at start gm.*	*Order*	*Increase in weight gm.*	*Order*	*Amount of milk gm.*	*Order*	*Efficiency Quotient, E.Q.**	*Ratio: inc. in wt. to Amt. of milk*
1	F	6,371	1	852	4	5,251	1	11·01	0·162
2	M	6,358	2	960	2	4,480	4	14·63	0·214
3	M	5,988	3	985	1	5,012	2	12·77	0·197
4	F	5,310	4	845	5	4,421	5	10·95	0·191
5	F	5,123	5	140	10	2,373	10	3·06	0·059
6	F	4,996	6	862	3	4,524	3	10·37	0·191
7	F	4,776	7	537	8	3,717	6	7·31	0·144
8	M	3,956	8	550	7	2,712	8	8·59	0·203
9	M	3,938	9	530	9	2,707	9	8·24	0·196
10	M	3,513	10	707	6	3,169	7	8·62	0·223
11	M	6,423	1	534	3	3,160	3	11·30	0·169
12	F	5,882	2	850	1	3,412	2	15·70	0·249
13	F	5,795	3	605	2	3,917	1	9·39	0·154
14	F	5,785	4	43	10	2,666	9	0·92	0·016
15	M	5,611	5	198	8	2,808	6	4·05	0·071
16	F	5,407	6	531	4	2,704	8	11·12	0·196
17	F	5,136	7	292	7	2,860	5	5·39	0·102
18	F	4,935	8	510	5	2,761	7	9·60	0·185
19	F	4,873	9	..	..	..	..	..	..
20	F	4,641	10	466	6	2,933	4	7·75	0·159
21	F	2,955	11	−126	..	883	11	..	..
22	M	2,566	12	186	9	1,496	10	3·30	0·124
23	F	2,025	13	..	..	..	..	..	..

* $\text{E.Q.} = \dfrac{\text{Increase}}{\text{Amount of milk}} \times \dfrac{\text{Weight}}{100}$; Weight = (initial weight + ½ live-weight increase during the experiment).

In this table the pigs are arranged in order by weight within litters, numbers 1–10 belonging to the older sow's litter and numbers 11–23 to that of the gilt. No. 5, which was lame, suffers as a result in comparison with the others. When the experiment began Nos. 19, 21, and 23 were falling behind their litter-mates in size and getting progressively less milk, so that they shortly became so weak that they stood no chance at all. At the end of the week they were still alive and responded rapidly to a little preferential treatment. In the sow's litter, the relation between size of pig, increase in weight, and amount of milk is quite close. In the gilt's litter it is also reasonably close, considering the defections and the failure of No. 14 to make much headway. On the whole, the conclusions of Carlisle [3], Bonsma and Oosthuizen [2], Thompson [4], and others, that the largest pigs in a litter obtain the most milk are borne out. There

appears to be an even closer proportionality between the increase in live weight and the amount of milk obtained, and the question arises whether the larger pigs with their greater rations are more or less economical than the smaller pigs. Bonsma and Oosthuizen were led by their data to ask the same question. As a first step towards the answer the last two columns were calculated, the Efficiency Quotient (E.Q.) after the manner of Palmer and Kennedy modified by Winters and McMahon



GRAPH 1. Relation between Live-weight Increase and Amount of Productive Milk consumed (maintenance of 2kg. pig for a week assumed to be 800 gm. of milk)

[5]. Now although according to E.Q. the largest animals were the most efficient, the same clear superiority was not shown when body-weights were left out of account, as in the last column. In order to reconcile these figures the question was approached from another angle, viz. by estimating the maintenance-requirement in terms of milk for each pig and using the quantity obtained in excess of this (called productive milk) for the efficiency calculation, efficiency being defined as the ratio of productive milk to live-weight increase, or the number of grams of productive milk required for 1 gm. live-weight increase. The smaller the number, the more efficient the pig. Unfortunately, determinations of the maintenance-requirements of such small pigs could not be found, and had to be deduced indirectly. As a first approximation it was assumed, after Schneider [6], that roughly 2 gm. of milk would be needed to give 1 gm. live-weight increase, and working backwards we obtain 1,000 gm. of milk as the approximate maintenance-requirement of a 2 kg. pig for a

week. Five values between 800 and 1,200 gm. were then tried to see which produced the most reasonable range of efficiencies. This was done by calculating the maintenance for each pig from each of the five basic maintenance-requirements from the formula:

$$\text{Maintenance-requirement} = M_b\left(\frac{W}{2{,}000}\right)^{0\cdot73},$$

where M_b = 800, 900, 1,000, &c.,
W = the initial weight plus half the live-weight increase of a given pig.

TABLE 4. *Comparison of Efficiency in Converting Milk to Live-weight Increase (excluding Nos. 14, 19, 21, 23)*

No. of Pig	*Sex*	*Weight*	*Live-weight increase*	*Basic maintenance = 800 gm. milk per week for 2 kg. pig*		*Basic maintenance = 1,000 gm. milk per week for 2 kg. pig*	
				Productive milk	*Efficiency*	*Productive milk*	*Efficiency*
22	M	2,659	186	511	2·75	265	1·42
10	M	3,867	707	1,875	2·65	1,551	2·19
9	M	4,203	530	1,331	2·51	987	1·86
8	M	4,231	550	1,330	2·42	984	1·79
20	F	4,874	466	1,400	3·00	1,017	2·18
7	F	5,045	537	2,145	3·99	1,752	3·26
18	F	5,190	510	1,157	2·27	756	1·48
6	F	5,427	862	2,866	3·32	2,452	2·84
5	F	5,193	140	767	5·48	366	2·61
17	F	5,282	292	1,234	4·23	828	2·84
4	F	5,733	845	2,695	3·19	2,264	2·68
16	F	5,672	531	992	1·87	564	1·06
15	M	5,710	198	1,087	5·49	657	3·32
13	F	6,098	605	2,111	3·49	1,660	2·74
12	F	6,307	850	1,562	1·84	1,099	1·29
3	M	6,481	985	3,125	3·17	2,653	2·69
2	M	6,838	960	2,518	2·62	2,027	2·11
1	F	6,797	852	3,297	3·87	2,808	3·30
11	M	6,690	534	1,229	2·30	746	1·40

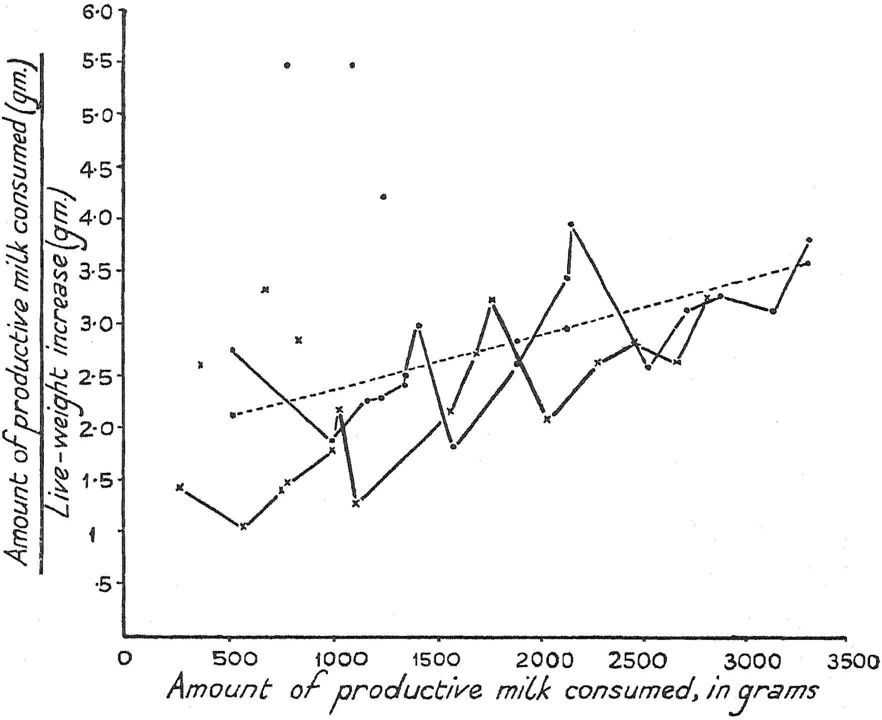
All weights in grams.

In accordance with the results of Brody, Procter, and Ashworth [7] the maintenance is presumed to be proportional to the 0·73 power of the live weights. The most reasonable results were given when 800 gm. was taken as the basis, the others resulting in efficiencies which appeared too high. As a check on these figures, the basal metabolism for a 2-kg. animal given by Brody, Procter, and Ashworth, viz. 117 Calories per day, was converted into grammes of milk per week. If 1 gm. of digestible milk nutrients is equivalent to 4 Calories, and if in sows' milk there are 25·5 per cent. total digestible nutrients, 803 gm. of milk per week would be required. This is sufficiently close agreement. The purpose being to expose differences in efficiency rather than the actual values, it does not greatly matter whether this is an accurate estimate or not, provided there is a basis for comparison. Table 4 and Graph 2 show that

even if 1,000 grams is used as the basic figure, there is little change in the relative performances of the pigs.

Table 4 provides a comparison of efficiencies estimated in this way.

The relation between the amount of milk available for growth and the actual increase in weight is brought out more clearly in Graph 1, which shows a strong correlation between the two. It also conveys the



GRAPH 2. Relation between Total Amount of Productive Milk Consumed in Seven Days and the Amount of it Required per Unit Live-weight Increase.

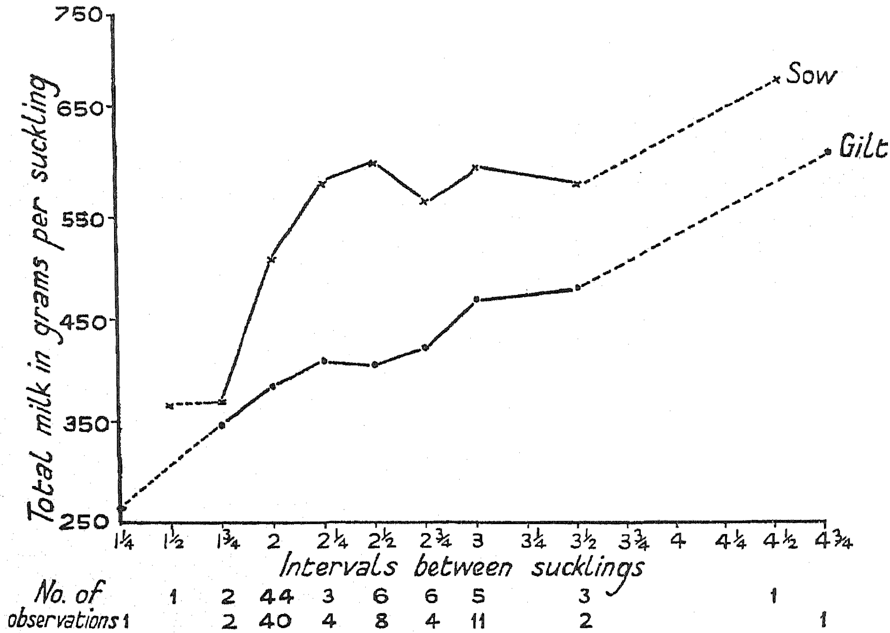
×——————×— maintenance-requirement 1,000 gm. milk per week for 2 kg. pig

·——————·—— ,, ,, 800 gm. ,, ,, ,, ,,

·- - - - - - -·- - - regression of $\frac{\text{productive milk consumed}}{\text{live-weight increase}}$ on amount of productive milk when maintenance-requirement is 800 gm. milk per week. The value of the regression coefficient is 0·52 for a change of 1,000 gm. in the amount of productive milk consumed, and its significance is beyond the 1 per cent. point. The calculation has not included the three aberrant results.

suggestion that the animals receiving the most milk in excess of their maintenance-requirements, were converting it less efficiently than those receiving less. By plotting productive milk against efficiency this can be detected more easily (Graph 2). If efficiency were the same for all levels of feeding, the curve should remain approximately horizontal. Since the curve drawn from the observations (but excluding three of them) shows a definite upward slope, it would appear to indicate that the pigs which

had the largest amounts of productive milk, were making less economical use of it than the pigs which had less. This conclusion is vitiated considerably by two of the three observations which were not introduced into the curve and have been shown separately. The third one was from the lame pig and could be justifiably omitted, but for the other two no suitable explanation is forthcoming. The pigs involved were Nos. 5 (the lame pig), 15, 17. The other two could not have possessed such low efficiency previously unless they had obtained relatively much more milk



GRAPH 3. Relation between Length of Interval between Sucklings and Amount of Milk obtained by the Litter.

than their litter-mates, or they would not have had so large an initial weight. Even if they were included in the curve of Graph 2, however, the rise would still be apparent although not as steep as shown.

Effect of time between sucklings on the amount of milk obtained.—Although the aim was to space sucklings at 2-hour intervals during the day, and at 3-hour intervals during the night, these could not always be exactly observed, so that there is a range of intervals of varying length for comparison of the total amounts of milk obtained by the litter. The results are shown in Graph 3. In addition to the obvious difference in the yield of milk from the sow and the gilt (from Table 3; total milk, sow 38·4 kg.; gilt 29·6 kg.), there is a clear indication of an increase in the amount of milk with longer intervals between sucklings: all the teats showed increased amounts. This is to some extent in accord with the results obtained with cows. At the end of the experiment the sow was giving rather more milk than at the beginning, and the gilt rather

less. This is entirely to be expected from normal changes during the progress of lactation, and there is no evidence that the unusual treatment 'put the sows off their milk'.

The figures available are scarcely adequate to show where lies the upper limit to the amount of milk which the udder can hold. Were it not for the two exceptionally long intervals the conclusion might have been drawn that these limits were probably in the neighbourhood of 600 gm. for the sow and 500 gm. for the gilt. That they can hold more than this is clear enough. The maximum for the sow at any weighing was 691 gm. and the gilt 635 gm., but these values might not represent the maximum determined from numerous observations. The explanation is favoured that the interval between sucklings affects the yield of milk, although another explanation is possible. Most of the long intervals occurred during the night, and the short ones during the day, so that if darkness were associated with higher yield, such an effect could not be separated from that due to the differences in length of the intervals.

Distribution of milk in the udder.—It has been pointed out on numerous occasions that the 'best' teats are the forward ones. That mere inspection shows this to be subject to exceptions does not detract much from its value as a generalization. Quite large differences in the yield of different sections of the udder which are not apparent to the eye would appear to exist. Not only in the two sows under discussion but in various others it has been noted that although it is possible to tell a manifestly good mammary gland from a poor one, it is not easy to place them all in their correct order according to yield. As an example the distribution of milk in the udder of the older sow is given in Table 5: similar data for the gilt are not presented as her pigs did not suck as consistently at the same teat. The last two pigs suckled a pair of teats each. Although the largest yield was obtained at the anterior end, there was in this case no clear gradation from one end to the other, nor was there close agreement between the yields from members of each pair of teats.

TABLE 5. *Distribution of Milk in the Udder of the Sow. Total Milk (in gm.) from each Teat for the Week of Observation*

Teat No.	*1 anterior*	*2*	*3*	*4*	*5*	*6 posterior*
Right side . . .	4,381	4,480	2,373	4,334	3,717	2,707
Left side . . .	5,201	3,169	4,862	2,572		

Discussion

The effect of an investigation such as this is to invite reconsideration of the importance of variability in weaning or 3-week weights. Differences in size among young pigs are probably useless for comparing their genetic qualities. Such differences as have been found, and even some deaths, can be satisfactorily explained by variation in the level of nutrition. These differences are disadvantageous not only from the point of view of husbandry, and economy, but they must remove the possibility

of making any early judgement concerning type, owing to the different relative growth-rates of the parts of the body at different ages [8].

The positive correlations between weights at various ages [9], which might be attributed to qualitative differences in the pigs, may merely measure the advantage at any age of superior weight. On the other hand the decrease in size of the correlation coefficients as the period between the weighings increases, must mean that advantage in weight is often lost. This may be accounted for partly by accidents, and partly by efficiency changes induced by variations in the quantity or quality of the food. The negative correlation between average daily gain from birth to weaning and weaning to slaughter found in calves by Black and Knapp [10] is probably evidence of the latter. It would be surprising indeed if the animals which were best fitted, in the genetical sense, for intra-uterine life, were also the best fitted for growth on a grain diet after so short a period of adaptation as has elapsed since modern feeding-methods were available.

That selection of animals in order to increase the average performance over the whole lifetime must be an exceedingly difficult and slow process, can be appreciated by considering for a moment selection for performance during a restricted period of life, such as the first three weeks after birth. As was shown in Table 4, there are considerable differences in the economy with which pigs convert their food into live-weight gain. Such differences, if genetic, might be due to relatively high or low maintenance-requirements, early or late onset of diminishing response to increments in the amount of food, and so on. Each of these possible causes could be further subdivided into numerous parts, such as variations in disposition to exercise, in chemical composition, and temperature-regulation. Ultimately large numbers of genes must be involved, and large numbers of different genotypes must have indistinguishable phenotypes. Even if the really superior animals could be detected, selective breeding could accomplish improvements only very slowly [11], unless some few genes with major effects prove to be involved. In that event, the prospect of accumulating them is much brighter, and the search for means of identifying them justified. Grounds for believing that this may be so, is provided by the experience of Morris, Palmer, and Kennedy [12], who were able to establish lines of rats significantly differing in rate of growth.

The foregoing results also suggest some comments on the use of litter-weights as measures of the milking-capacity of the sow. If the subjects of the present experiments exhibit the working of a general law of diminishing response to increments of food, the fact would have to be recognized in evaluating the performance of sows and litters. Although the relative decrease in maintenance-requirement with increasing weight offset to some extent the loss of efficiency in the pigs which received the most productive milk, the effect was not considerable when the rate of growth was reasonably rapid. A difference of 1 kg. in weight between two light pigs in a litter would therefore represent much less milk than the same difference between two heavy pigs. This could account for the comparatively small reduction in the average weight at

three weeks with increasing litter-size shown by Johansson's data [13]. It seems probable that the average amount of milk per pig would show a much greater reduction with increasing litter-size.

If experience with milking cows counts for anything in breeding for milk-production in pigs, it is most desirable to obtain outstanding performers for grading up a herd. It may be unfortunate that these should have to be detected by means of the weights of their litters, for unless the herd performance is rather low, the differences in milk-yield between good and outstanding sows may not be associated with corresponding differences in litter-weights. Considering possible variations in litter-size and number, seasonal fluctuations, and accidents, they may well be undetectable. Another consequence of these results would be that litter-weights must mask to some extent (obviously not completely) the actual range of variation occurring in milk-production. Still more justification would then be forthcoming for drawing an analogy between present herds of breeding sows and the herds of milking cows of pre-testing days.

Since small pigs are more economical converters of solid food than their mothers, there would be no point in striving after phenomenally productive sows except for breeding purposes. All that is required is that a sow shall have milk enough to carry her pigs through the stage of transition to solid food without check. This means that not only the peak production as measured by three-week weights, but also persistency as measured by later weights, should be considered. It may well be that in the future the suggestion of Asdell [14] that the inheritance of the components of milk-yield rather than total yield should be studied, will have to be heeded.

Summary

1. An experiment is described in which two litters of Large White pigs were weighed individually before and after each suckling for a week. A close association was found between the live-weight increase and the amount of milk consumed.

2. One sow which was nursing 10 pigs in her third litter gave over 30 per cent more milk than the other sow which had 12 pigs in her first litter.

3. In general the largest pigs in a litter obtained the most milk. If certain assumptions are made concerning the amount of milk required for maintenance, the pigs which received the most milk in excess of their maintenance-requirements appear to have converted it to live-weight increase less economically than their litter mates.

4. As the interval between sucklings lengthened, the amount of milk obtained by each pig increased. For one of the sows the actual production for each nipple could be ascertained and showed great irregularity. The anterior nipples tended to be more productive than the posterior.

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SUCKLING AND SUCKLING PREFERENCE IN PIGS

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It is often asserted that during the suckling period each member of a litter 'has its own teat', i.e. suckles regularly at a particular nipple. This 'suckling preference' is not without practical interest, for it would mean that some pigs in a litter would obtain very much less milk than others since different gland sections of the udder may secrete very different quantities [1]. There is, however, little or no information concerning the extent of this preference. As it has an obvious bearing on the variability of litter-mates, a problem which is receiving attention in the Large White herd of the University of Edinburgh, a series of observations has been carried out to provide an estimate of its significance. Some preliminary experiments have also been made to determine what factors influence the choice of nipple; the results, although not particularly important in themselves, suggest that the sow and litter provide a most interesting and instructive material in the study of animal behaviour. In addition to an account of these observations and experiments, the present paper includes some comments on the process of suckling, which has been frequently and closely watched.

The term 'suckling preference' disguises the fact that there are at least two kinds of preference, which may or may not be antagonistic. The first is shown by all pigs from the moment of birth in their attempts to attach themselves to the anterior rather than the posterior nipples. The reason for this will be discussed later. Tsai [2] found that young rats suckled most frequently at the fourth pair of nipples. He suggested that, having regard to the suckling attitude of the female rat, this pair was the most accessible. This type of preference is distinguishable from the second type, which markedly affects the distribution of pigs along the udder of a sow, and arises from a desire among pigs to suckle each at a particular nipple, a desire which apparently does not exist in litters of rats. Suckling preference in this sense has been referred to by many authors including Carlisle [3], Hempel [4], Bonsma and Oosthuizen [5], Hugenroth [6], Fishwick [7].

Material and Method

The sows and litters upon which the following observations were made included some which were utilized also for obtaining estimates of milk-production and were therefore of a quiet disposition, but otherwise there is no reason to suppose that the results may not be typical. The pigs were recognized with the aid of spots painted on them. It was not always possible to make observations of undoubted accuracy; sometimes the sow would be fidgety; sometimes a pig would try several teats; and sometimes it would be obscured by a litter-mate. Errors of observation arising in this way are not considered sufficient to make any real

difference to the results, nor are errors due to the impossibility of being sure that pigs in the lower row were actually suckling a nipple when observed.

Results

Altogether 97 sets of observations have been made on 5 sows with litters. As almost any one litter would serve to illustrate the main conclusions of this study, it is not proposed to present the whole of the data nor any of the more fragmentary observations which support the results obtained. The data contained in the following tables do not therefore represent the complete material on which the conclusions are based.

Table 1 clearly shows that there is a firm foundation for the belief that each pig in a litter 'has its own teat'. To simplify matters, only those observations were included during which the sow was lying on her right side. The 'correct' positions of the pigs have been assumed to be those most commonly occupied, and have been distinguished as R1, R2, ... R6, on the right side, and L1, L2, ... L6, on the left side. Pigs with R positions were therefore suckling the nipples next to the ground.

TABLE 1. *Positions occupied by the 10 Pigs (aged 3–4 weeks) in the Litter of Sow A during 21 Sets of Observations (Sow lying on her Right Side)*

Pig No.	*Weight*	*Correct position*	*No. of times*		*Incorrect Positions*
			Correct	*Incorrect*	
	kg.				
1	6·7	L1	21	0	
2	5·6	R1	20	1	R2
3	3·8	L2	20	1	L3
4	6·6	R2	17	4	L2, R3, R5, R1
5	6·3	L3	19	2	L2, R2
6	5·2	R3	16	5	R2, R4 (2), L4, R5
7	4·2	L4	21	0	
8	5·3	R4	19	2	R3, R5
9	4·9	L5, R5	21	0	Yielded R5 on occasions to Nos. 4, 6, 8.
10	4·1	R6, L6	21	0	
		Total	195	15	

Nos. 9 and 10 each suckled a pair of nipples.

When a wrong position was taken up by one pig, another pig was usually but not always, also out of position. In some instances, two pigs would endeavour to obtain the same nipple, and only one mistake was deemed to have been made if one of the pigs was the rightful owner. Disagreement of this kind occurred usually when one pig could not find its own or a vacant position and attempted to take another by force. The tenacity with which the original occupier would resist such invasion and refuse to be satisfied with any other position is to be contrasted with a much greater readiness to suckle the 'wrong' teat when unable to find its own.

The general conclusion that the pigs at either end of the udder are rarely found out of position is well illustrated by this litter. Most of the

errors have been committed by Nos. 4 and 6, the other pigs being forced into secondary errors. In all litters the pigs centrally placed were most often at fault, suggesting that it is more difficult to find a correct position in the middle than at the ends of the udder. In this particular litter, it is not without significance that Nos. 4 and 6 belonged to the lower row of teats, for their difficulties were thus increased.

It will be observed that most of the errors were horizontal ones, i.e. when a pig did take a wrong nipple, it chose one in the row in which it customarily suckled. From this it may be supposed that a habit of suckling either standing or crouching may be formed by some pigs. This conclusion would not have been so clear if this particular sow had not been in the habit of lying on her right side. It is to this habit that the comparatively low percentage of errors found in this litter can be attributed. What was involved seemed less to be 'right-sidedness' than good mothering, for the sow frequently lay down on her left side, but only once in 24 recorded sucklings actually suckled her pigs that way. Whenever she lay on her left side there was much confusion amongst the pigs, and she regularly got up and lay down on her right side to cure it. Although the figures are not extensive enough to prove it, there is a strong suspicion that some of the other sows were also more inclined to lie more often on one side than the other. One sow (B), for instance, was observed seven times on her left and twice on her right; her eleven pigs made no errors at all while she was on her left, but re-arranged themselves to some extent when she lay on her right.

An interesting point is raised by the nature of the re-arrangement occurring when a sow which lies usually on one side, tries the other. It might be expected then that a pig which had become accustomed to standing in the upper row of nipples or to lying in the lower row, would have to choose between retaining its accustomed nipple or its accustomed position. On the five occasions on which the pigs in the litters of Sows A and B were observed making this choice, about half the pairs elected to change sides and retain their own nipples, and about half took up their usual positions and accepted the strange nipples. Since they were not consistent in their choices, it would appear that both position of body and recognition of nipple as well as the appreciation of horizontal distances play a part in determining the disposition of pigs at suckling.

The behaviour of a litter under rather more complicated circumstances is recorded in Table 2. In this case the sow (C) was raising her first litter of nine pigs together with four others which had been transferred to her for another purpose. She differed from Sow A in several respects. She lay readily on either side, she turned a deaf ear to fighting amongst her pigs, and she presented a smaller udder to thirteen pigs as compared with the ten of Sow A, on a large udder. Three sets of observations were made at intervals of about a fortnight, the first being made on the fourth and fifth days after farrowing.

There can be little doubt that as early as the fourth day after farrowing, the litter had distributed itself into positions that were retained for the most part until at least one month later. The extent to which this litter

gradually became more accurate in discovering the appropriate positions may be roughly measured by the percentage of the observations at each age which agreed with the 'correct', i.e. the most common, position at one month old. At 4–5 days old 40–50 per cent. of the observed positions were the same as the 'correct' positions at 1 month old; the corresponding value at 2 weeks old was slightly more than 50 per cent., and

TABLE 2. *Positions occupied by the Pigs in the Litter of Sow C as observed at Three Different Periods of Suckling Separated by Intervals of about a Fortnight*

(Column 2 shows on which side sow was lying)

No. of pig	*	*20/4–21/4*		*2/5*		*16/5–20/5*	
1	R	R1 (4) L1 (2)	6	R1 (6)	6	R1 (9)	9
	L	R1 (2) L1 (1)	3	R1 (1)	1	R1 (10)	10
2	R	L1 (4) R1 (2)	6	L1 (6)	6	L1 (10)	10
	L	L1 (2) R1 (1)	3	L1 (1)	1	L1 (9)	9
3	R	L2 (5) L3 (1)	6	L2 (6)	6	L2 (7) L3 (1)	8
	L	R3 (3)	3	R2 (1)	1	R2 (7) R3 (2)	9
4	R	R2 (4) R4 (1) L2 (1)	6	R2 (3) R3 (2) R7 (1)	6	R2 (6) R3 (4)	10
	L	L2 (2) R2 (1)	3	L2 (1)	1	L2 (8) L3 (1)	9
5	R	R3 (4) R4 (2)	6	R3 (2) R4 (2) R2 (1) R5 (1)	6	R3 (4) R4 (2) R2 (3)	9
	L	L3 (1)	1	R3 (1)	1	R3 (6) R2 (1) L2 (1) L3 (1) L4 (1)	10
6	R	R2 (2) R5 (1) R4 (1)	4	R6 (3) R5 (2) L3 (1)	6	L3 (8) R1 (1) L2 (1)	10
	L	L3 (2) L2 (1)	3	R7 (1)	1	L3 (6) L2 (1) R4 (1) R5 (1)	9
7	R	L3 (4) R4 (1) L6 (1)	6	L3 (3) L4 (2) R4 (1)	6	R4 (4) R3 (2) L2 (2) R2 (1)	9
	L	R4 (2) L4 (1)	3	R4 (1)	1	R4 (7) R2 (1)	9
8	R	R3 (2) L3 (1) R5 (1) L5 (1)	5	R3 (2) R4 (2) L3 (1) R5 (1)	6	L4 (8) R4 (1)	9
	L	L4 (1) R2 (1) L6 (1)	3	R5 (1)	1	L4 (3) R4 (1) R5 (1) R6 (1)	6
9	R	R6 (2) L4 (2) R4 (1) R5 (1)	6	R5 (2) R6 (2) L5 (1) R7 (1)	6	R5 (8) R4 (1) R6 (1)	10
	L	R5 (2) R6 (1)	3	L3 (1)	1	R5 (6) R4 (1) R6 (1) L4 (1)	9
10	R	L4 (3) L5 (2) R6 (1)	6	L5 (6)	6	L5 (8) R4 (1)	9
	L	L5 (2) R6 (1)	3	L5 (1)	1	L5 (6)	6
11	R	R7 (4) R5 (1) L5 (1)	6	R7 (4) R6 (1)	5	R6 (1) R5 (2)	3
	L	R6 (1) R7 (1) L5 (1)	3	R6 (1)	1	R6 (6)	6
12	R	L6 (4) R6 (1) R7 (1)	6	L6 (6)	6	L6 (9) R7 (1)	10
	L	L6 (2) R7 (1)	3	L6 (1)	1	L6 (8) R7 (2)	10
13	R	R6 (1) R7 (1) L5 (1) L6 (1)	4	L4 (3) R2 (1) R4 (1) R7 (1)	6	R7 (4) L3 (1)	5
	L	R7 (1) R4 (1) L4 (1)	3	L4 (1)	1	R7 (4) L6 (1) R2 (1)	6

at 1 month old it was 75–80 per cent. This last value indicates that on 20–25 per cent. of the occasions at 1 month old, the pigs made wrong choices, a figure which may be compared with the corresponding one of 7 per cent. for the litter of Sow A. The earliest errors, it may be noted, have arisen largely from the fact that the pigs exchanged nipples more often than positions as the sow turned from one side to another. In most litters of about 1 month old, there is usually one pair of pigs, at least, which retain this early habit of exchanging nipples, e.g., Nos. 3 and 4 in Table 2.

The exceptionally large number of errors made by the pigs in this litter may be attributed to some, or all, of the following causes:

(*a*) The milk supply for this first litter of thirteen was inadequate, so that the pigs were often hungry, particularly when they reached three weeks of age. In this condition they were less inclined to insist on having the correct nipple.

(*b*) The litter eventually became so large in relation to the length of the udder that it was very difficult for a late-comer to insert itself into the right place even if it knew where it was.

(*c*) The presence of two pigs in the litter which often did not suckle (Nos. 11 and 13) provided opportunities for others to appropriate the spare nipples.

(*d*) The number of nipples was not the same on both sides of the sow, the fourth on the right being unpaired. The process of assorting themselves was therefore more complex for the pigs as the sow changed from one side to the other.

(*e*) Unlike sow A, sow C did not wait until all her pigs had found their proper places before letting down her milk, and thus encouraged them to trouble less about which nipple they were actually suckling.

These facts indicate that the chief means by which a pig finds its own nipple is by an appreciation of the conformation of the sow as a whole (in the sense of the *Gestalt* theory). To watch a litter of hungry pigs go through the process of suckling is to realize the remarkable accuracy with which they sort themselves out. There is no question of trying in various places until the right one is found. They go directly to the right place. This ability must be founded mainly on sight, with some capacity to recognize the feel of a nipple playing a secondary part. Hearing may be disregarded, and so may a sense of smell, for pigs placed with a foster mother will, if they are able, take up the positions they had on their original mother. An udder, moreover, which is coated with mud or some smelly substance does not appear to affect the positions of the pigs.

Another possibility, which does not seem to be important, is that the pigs may find their way by recognizing their neighbours. This clearly cannot apply to them all, and if the following short test of this possibility is generally valid, it does not apply to any. On four occasions, different pairs of pigs from the litter of Sow C which had been removed from their mother two hours previously, were put back with her before the remainder of the litter. Each time the pigs went directly to their own nipple and suckled, trying other nipples in a furtive manner when they realized they were not being used, and obviously keeping a watchful eye meanwhile on their own.

There is a peculiar habit, often exhibited, which may be of importance in orientating the pigs, although there is no reason to suppose that it is essential. This is the habit of communicating, snout to snout, with the sow before starting to suckle. A more probable explanation, which is also favoured by Shepperd [8], is that it is to encourage the sow to liberate her milk, especially since it occurs after suckling as well as before. A test in complete darkness should yield useful results.

Reviewed briefly, suckling preference in pigs arises very early in life, mainly from a desire to occupy always a particular position. Later comes recognition of particular nipples. Departures from the normal distribution appear to be associated most commonly with large litters, lack of uniformity in the udder, and certain kinds of maternal behaviour. In the first day or two the tendency to keep to the anterior glands of the udder is stronger than the desire to retain a particular position; but the inference that the pigs must be capable of estimating the milk yield from the various nipples, and therefore 'choose' the anterior nipples, is not easily justified. A more probable explanation is that these nipples are in a much safer region, being farther away from the hind legs of the sow. Apart from this general tendency to move to the anterior part of the udder, little evidence has been found that young pigs 'choose' their nipples. The impression has been gained that the original distribution is largely due to chance, depending more on the times at which the pigs begin to suckle at one nipple than on their relative weights. In general, nevertheless, the largest pigs will be found suckling the anterior nipples, for, whatever their initial weight, they obtain most milk and will quickly become the largest.

The variation in the weights of litter-mates, which has at times interested various investigators, must for the present be regarded as requiring little or no genetic explanation. Given mammary glands of considerably different productivities, an efficiency in utilizing milk which varies according to the quantity consumed [1], and a strong tendency for each pig to suckle at only one nipple, there may be no need to postulate genetic differences in growth-rate. Although such differences probably exist, the observed variation must be mainly an effect of inequalities in the milk-yield of the mammary glands of the udder. The problem then resolves itself into determining whether it is possible, by selection, to remove these inequalities.

The Process of Suckling

Three distinct stages may be recognized. The first is a preliminary period during which the litter sorts itself out and stimulates the flow of milk by massaging the udder. At this time also many of the pigs may run round and touch the snout of the sow. Quite suddenly the second stage begins during which the pigs suckle rapidly and do not massage. The third stage follows shortly and consists usually of an extended repetition of the first but includes rather more actual suckling. All stages are of varying length; the third may extend to 15 minutes or more; on the other hand it may be practically eliminated. There is reason to believe that little or no milk is obtained during the third stage, for if the pigs are weighed immediately after the second, the increase is just as great as it is when they have been allowed to remain for some time longer with the sow. On several occasions the pigs have been returned to the sow for 15–20 minutes after removal at the end of the second stage, and went through what appeared to be the third stage. With one or two doubtful exceptions all the pigs lost weight slightly during this time. Whether

or not this result is pertinent to the question depends on whether suckling proceeds normally under such treatment.

The second stage was found to be shorter than might be expected. It is not always possible to secure a trustworthy measure of the time, but Sow A and her litter, referred to previously, behaved in a sufficiently regular and well-defined manner to provide a good estimate. The length of the second stage varied between 35 and 45 seconds, which means that the milk must have been liberated at a very rapid rate. On the average 50 grams of milk passed from each nipple in 40 seconds. As an average this may be comparatively high, but there must be many nipples which exceed it.

All the evidence available supports the view that some pressure mechanism must be responsible for the 'letting down of the milk'. It is in fact difficult to conceive so much milk being merely sucked through a soft collapsible tube in so short a time, and in any case, unless some stimulus is applied (except at or near farrowing) it is not possible to obtain more than a few drops of milk by hand. If a stimulus is applied either by rubbing the udder or by allowing one or two pigs of a litter to suckle, milk is easily obtained, and may often be seen to trickle from the more productive nipples. Hammond [9] has dealt at length with this subject and expands the theory that under stimulus an 'erection' of the udder occurs which provides the necessary pressure to force out the milk. Although the data now presented are not sufficiently critical to indicate whether or not there is a contemporaneous acceleration of the rate of secretion, the very short period of suckling, and the increased amount of milk obtained with increasing intervals between sucklings [1], are quite compatible with the erection theory alone.

Hammond's review also suggests that the significance of the third stage of suckling may lie in a changed composition of the milk which is withdrawn towards the end of suckling. It may be that the small quantities of milk obtained last are richer in fat and other milk constituents. Whether this is the explanation for the third stage or not, it is noteworthy that this stage is widespread in many kinds of animals, and does not appear to be merely an indication of unsatisfied hunger. Young pigs which have obviously had enough will go on suckling although the skin is stretched tight around them. Causal factors will no doubt be found to account for the frequency of suckling, the amount of milk secreted, the stages of suckling, and the varying composition of the milk.

Summary

The extent to which differences in the milk-yield of different mammary glands in the same udder will be reflected in varying weights of the litter-mates depends on the extent to which the latter confine themselves to suckling particular nipples. Data are presented which indicate that although strong preferences do exist among the members of a litter, they cannot always be satisfied. The chief factors influencing the number of departures from the normal distribution at suckling appear to be: (*a*) the number of pigs in the litter, (*b*) the suckling behaviour of

the sow, and (*c*) the uniformity (or lack of it) in the udder. It is suggested that during the first few days after farrowing the pigs become capable of recognizing their positions in relation to the conformation of the sow as a whole, and that they later become accustomed to seeking the proper nipple in the upper or lower row as the sow changes from side to side. The period during which the milk is 'let down' by the sow appears to be very short (less than a minute), and it is concluded that all the observations made so far on the process of suckling can be well accounted for by the 'erection theory'.

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SOURCE OF SEED AND YIELD

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It has long been a belief among practical agriculturists that the importation of seed from a different locality is a beneficial practice. The question has, however, always been open to debate and has never received satisfactory proof or disproof from careful experiments. Information on the subject which merits attention is contained in a paper by Atkinson and Love [1]. They conclude: 'While it may be unwise to generalize from these data, it is clear that, so far as this pure line of oats is concerned, the environment under which the seed develops does not have any measurable effect when the seed is grown in a new locality.' Nevertheless a critical survey of their data indicates that Montana seed grown in New York produced more vigorous plants than did the home-grown seed, although New York seed seemed, on the average, no better than the home-grown in Montana.

The negative conclusion arrived at by the authors appears to be due to their having made comparisons year by year only without attempting to combine all the information, and because they appear to think that in comparison with the differences between localities the differences due to seed lots within localities are scarcely worthy of consideration. Since, however, it is possible that different fields in one and the same locality might show differences greater than any that might be due to variety or locality of seed, this difference should not be allowed to overshadow one which is yet of agronomic importance.

Seed of a pure line of Sixty Day Oats was grown in Montana and in New York from 1912 to 1919; beginning with 1915, seed imported from the other of the two places was grown for comparison with the home-grown seed. The data are based upon individual plants, and in the absence of information about the arrangement of the plots we cannot know whether the errors appended to the figures are applicable for inter-plot comparisons or represent only variability of plants within plots. To avoid assuming more information than may be valid for the data, we shall assume that in each year there was only one plot for each source of seed. If plots were in fact replicated this assumption will cause no error, but information will be lost, since a more accurate estimate of experimental error may be obtainable, and we could seek for evidence of interaction of treatment effects with years.

Total yield of grain is of major interest. The paper gives only yield per plant so we have to assume that both lots of seed germinated equally producing equal numbers of plants per area. The relevant data are given in Table 1. The results for other attributes are shown in Table 2.

Although not thoroughly proven it appears probable (odds about 30:1) that on a New York field which was somewhat low in fertility

[1] Formerly assistant research officer in the Council for Scientific and Industrial Research, Canberra, Australia. This paper was written in 1930–1, and subsequently mislaid. So far as I know, however, no important work on the subject has been published since the paper by Atkinson and Love.

Montana seed was better than seed from the same home field. In Montana both lots of seed seemed equally good on the average of five seasons, or interaction with seasons was so great that no consistent average effect can be demonstrated from these data. The observed gains were 9·1 per cent. of the mean yield in New York, 2·0 per cent. in Montana.

Since all trials were on the same two fields every year, the difference cannot be taken to represent Montana *versus* New York seed, but only seed from a good Montana field *versus* that from a low-grade New York field. The important point is that a positive effect in *some* circumstances is indicated, and therefore experiments to ascertain in *what* circumstances are to be encouraged.

TABLE 1. *Means of Total Weights of Kernels per Plant (in grams)*

Year	*New York*			*Montana*		
	Home seed	*Montana seed*	*Difference*	*Home seed*	*New York seed*	*Difference*
1915	4·280	4·337	0·057	9·576	9·758	0·182
1916	3·537	4·070	0·533	16·590	19·943	3·353
1917	2·922	3·357	0·435	17·997	16·080	−1·917
1918	3·225	3·555	0·330	14·138	14·592	0·454
1919	1·945	2·110	0·165	11·763	11·110	−0·653
Average			0·304			0·284
St. error			0·0868			0·87
	$t = 3{\cdot}51$; $n = 4$. $P < 0{\cdot}03$					$P = 0{\cdot}8$

TABLE 2. *Mean Differences between Plants from Away-grown and from Home-grown Seed.* 5 years, 1915–19

Attribute	*Gain over Home-grown Seed*	*St. Error*	*t*	*P*
New York grown				
Number of culms	0·113	0·0403	2·80	0·05
Length of culm, cm.	1·98	0·513	3·85	0·019
Length of head, cm.	0·240	0·103	2·33	0·09
Number of kernels per culm	3·530	1·14	3·09	0·04
Weight of grain per culm, mg.	51·0	18·98	2·69	0·06
Average weight per kernel, mg.	−0·008	0·126	0·06	High
Montana grown				
Number of culms	0·301	0·442	0·7	0·5
Length of culms, cm.	1·132	1·53	0·7	0·5
Length of head, cm.	0·272	0·163	1·66	0·2
Number of kernels per culm	0·061	1·19	0·06	High
Weight of grain per culm, mg.	30·0	27·3	1·10	0·4
Average weight per kernel, mg.	0·107	0·201	0·53	0·6

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THREE ECOTYPES OF *PENNISETUM CLANDESTINUM* HOCHST. (KIKUYU GRASS)

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WITH PLATE 11

IN recent years *Pennisetum clandestinum* has assumed considerable importance in literature dealing with pasture problems in tropical parts of the world. It has been introduced into most countries within the tropics and, in a number of them, it has given encouraging results. Successful trials have also been reported from the moister regions of the sub-tropics. The common name of the grass is derived from a comparatively small area in the highlands of Kenya occupied by the Kikuyu tribe.

The natural distribution of this grass is very limited and is confined to areas of particular moisture and temperature conditions. These areas have already been described by the writer [1].

In tropical East Africa, at altitudes roughly between 6,500 and 10,000 ft., and under a well-distributed rainfall of not less than 40 in. per annum, Kikuyu grass forms a well-defined phase in a succession of vegetation. The grass occupies the land for a period following clearance of the forest climax and, if the return of forest is prevented, remains in possession until the soil fertility falls below the required level, when it is followed by phases dominated by other grass species. Under grazing conditions *Pennisetum clandestinum* forms a closely matted sward, and a considerable proportion of *Trifolium Johnstonii* Oliv., the indigenous clover of these climatic areas, usually makes its appearance.

The grass is strongly stoloniferous and rhizomatous, and thrives under heavy grazing, producing high leaf-yields. It is recognized to be of great value for pasture, but its special climatic requirements prevent it from being used with success outside limited areas, even in East Africa.

The isolation of different strains of the grass is an obvious direction in which to look for the means to extend its use to wider areas. In this connexion, the possibility of different types existing in the effectively separated areas where Kikuyu grass occurs naturally is of particular interest. These areas are practically islands of special climatic conditions existing on masses of elevated land separated by lower-lying regions of dissimilar climate. In the search for types, therefore, material was obtained from several such localities and from the marginal regions around them.

In Kenya the extent of the vegetational area concerned is estimated at 7,000 to 8,000 square miles, and it exists in six main masses with a number of smaller ones. The main masses are: (1) an area from Molo, in the south, to north of Sergoit, (2) the ridge of highlands extending from Kikuyu through the Kinankop Plateau, (3) a region about Mount Kenya to the south and east of the mountain, (4) an area south-east of Mount Elgon, (5) an area about Kericho towards the west, and (6) the

Upper Gilgil district lying approximately midway between (1) and (2). These areas are shown on the map which accompanied the paper mentioned above [1].

Material from seven different areas, including five of those mentioned, was placed under observation with a view to discovering possible types. Three groups showing distinct characters were found, and these were named according to the areas of origin, namely, Kabete, Molo, and Rongai.

The noticeable differences between the three groups are: (*a*) A distinct difference in colour of the leafage; Kabete and Molo are of a light green, whilst Rongai is of a much darker green. (*b*) The leaves of the Molo type are narrow and the herbage has an appearance of fineness; the leaves of Rongai are broad and coarse, and those of the Kabete type are intermediate. (*c*) The creeping stems of the Molo strain are slender in comparison with those of the Rongai strain, and Kabete is again intermediate. (*d*) The mode of recovery, after cutting, of the three types is distinctly different. (*e*) Marked differences in habit of flowering are to be found from one type to another.

With regard to (*d*), observation of single plants of the Molo type showed that maximum growth of herbage occurred near the centre of the plant, in the region of the original rooted cutting, and the plots assumed a domed appearance. In the Rongai type, growth was more rapid towards the ends of the creeping stems, resulting in a scooped-out appearance of the plots, whilst the Kabete strain produced a more or less even growth over the whole surface occupied by the plant. These observations were made on replicated plots established from single cuttings planted six months previously.

The photographs (Plate 11, Figs. 1–3), show single plants of the three types, which were started from cuttings on April 11, and photographed on September 5, 1935. The areas covered are indicated by the cords laid over the plants to show the square feet.

In the early stages of the work on these types of Kikuyu grass an attempt was made to find a measurable difference between them, which might at the same time have some bearing on their economic possibilities. Using single plants, records were made of rate of growth of the creeping stems, the number of branches per unit length, and the average weight and dimensions of the leaves; but all these factors were found to be too variable to give any significant results. Later a randomized block of small plots was established for the purpose of determining the seasonal yields under a schedule of monthly cuts. This experiment is, as yet, incomplete, but in the course of the work differences in habit of flowering have been observed which appear to imply the existence of strains of this grass, and therefore warrant recording.

The flowering of *Pennisetum clandestinum* in general is peculiar, in that it has consistently been observed to take place only in short herbage. The usual appearance of flowering presented by the majority of grass species does not occur. No conspicuous flowering stems appear, and the only visible evidence of flowering is a bluish-white tinge over the surface of the sward, produced by the exsertion of the anthers, which are borne

on filaments up to 25 mm. in length. The stigmas are short and inconspicuous.

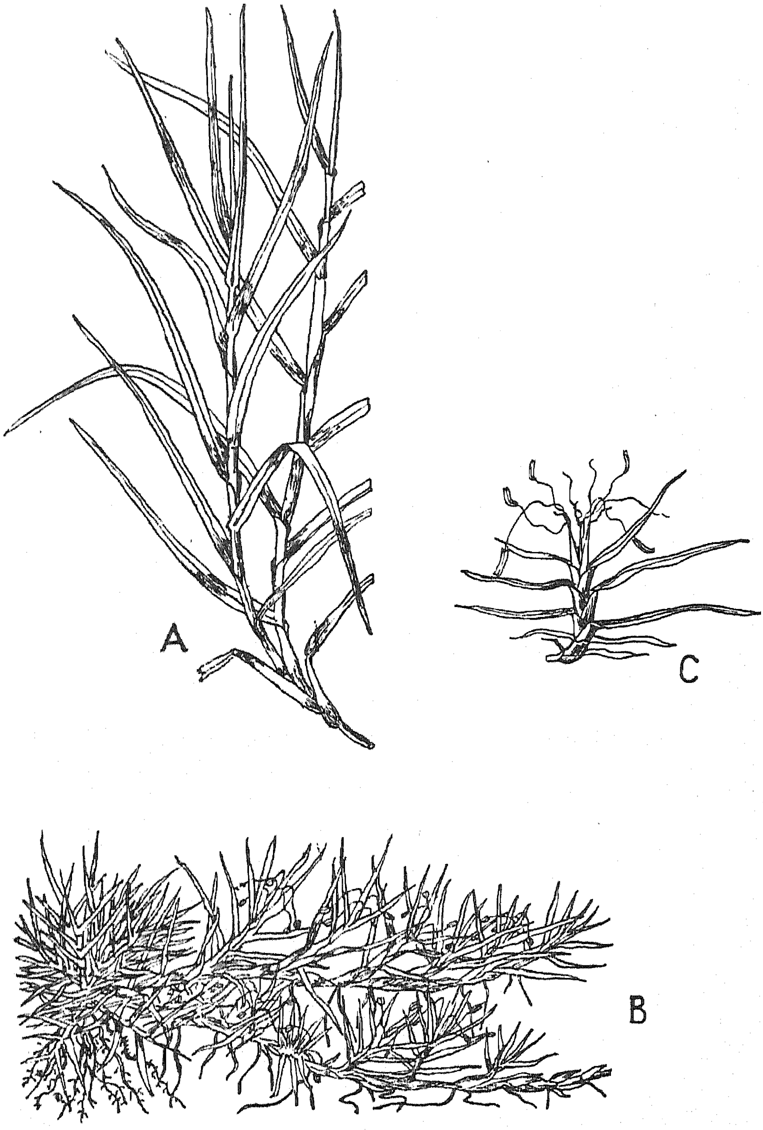

FIG. 4. *Pennisetum clandestinum.* A and B types of habit, C flowering shoot (all reduced). (From *East African Pasture Plants*, by kind permission of the Crown Agents for the Colonies.)

The spikelets are borne in clusters on short side-shoots growing from the stolons, and are almost enclosed by the uppermost leaf-sheath. The seed is formed practically at ground-level, and is therefore exceedingly difficult to obtain in quantity. For this reason the grass is normally propagated by means of stem-cuttings.

On a soil rich in organic matter, under optimum climatic conditions, the side-shoots may attain a height of 12 in. or more. In such circumstances, however, flowers have not been found. Occasionally, in such long herbage, a creeping stem with short flower-bearing shoots may straggle over the mass, although this does not frequently happen except where adverse factors, such as lack of sufficient moisture, operate. Where the grass has formed a dense mat of short herbage, either naturally or under the influence of grazing or cutting, prolific flowering takes place.

The spikelets occur in clusters of from two to four, the normal number being three. As already described, the flowering of the grass would be very inconspicuous were it not for the long, light-coloured filaments of the anthers. The terminal spikelet is shortly stalked and the others are sessile. Each consists of two florets 1–2 cm. long; the upper floret is perfect and the lower one has only the valve (flowering glume) present. In all cases the stigmas are exserted before the anthers and, in the same flower, the stigma has withered and has often disappeared before the three anthers are exserted.

Both the stigmas and anthers are exserted (in different flowers) during the night, and by about noon the next day they have been shrivelled by the sun. This applies less to the stigmas, some of which may persist longer, because they are partially sheltered by the short herbage, whilst the anthers are borne above it on their long filaments. The following observations therefore apply to a daily exsertion of these organs.

Detailed observation of the three types, Kabete, Molo, and Rongai, in herbage kept short by monthly cuts has shown the differences in flowering referred to above. In the first two types anthers appear over the whole surface of the plots within 24 hours of cutting the grass, and continue to appear indefinitely during the growing-season so long as the herbage remains short. These two differ, in that the Molo type exhibits distinctly less flowering, as shown by the appearance of anthers. In these two types, the stigmas which are exserted in some flowers concurrently with the anthers in others, immediately after cutting, are very little in evidence, but increase later in proportion to the anthers, and appear to reach a peak of production, which is followed by a further flush of anthers.

Observation of the Rongai type over a considerable period has shown that stigmas only are exserted. Flowering is therefore much less conspicuous, and can be observed only by close inspection of the herbage. During the period from September to January, careful and frequent examination of the plots of this strain has revealed not a single case of the exsertion of anthers, whereas the Kabete and Molo strains, under the same conditions, have produced anthers in abundance. The stigmas of the Rongai type appear, after cutting of the herbage, more slowly than the anthers of the other two types, but eventually become sufficiently plentiful to indicate that flowering is at least equally abundant.

Examination of the flowers of the three types has cast some light on this difference of behaviour. In flowers of Kabete and Molo, in which the stigmas are freshly exserted, the anthers are found at the base, and

apparently elongation of the filaments does not begin until fertilization, as indicated by enlargement of the ovary, has taken place. In flowers where the protruding stigmas are shrivelled the anthers are found near the top of the floret, and at a still more advanced stage of development the stigmas have frequently disappeared and the anthers are exserted.

In all florets of the Rongai type the anthers have been found on short filaments near the base. Ripe anthers have never been observed in this type and, in the older florets, the anthers have been found to be shrivelled and evidently not to have functioned. Also, in the older florets, the ovary has in most cases collapsed, is discoloured, and no fruit is formed. This last condition is, however, evidently not without exception, as ripe seeds have been obtained in very small quantity from this strain. It appears most probable that these seeds have been produced by cross-pollination from nearby plots of the other strains.

The three types of flowering may be summarized as follows:

Kabete. Immediately after cutting, this type produces abundance of anthers over the surface of the sward.[1] About 5 days later stigmas appear sparingly. These increase in proportion until they are approximately equal in number to the anthers, and then anthers again become preponderant, about 22 days from cutting.

Molo. Scattered florets exsert anthers in the first few hours after cutting, and some days later stigmas appear in about equal quantity. By the fourteenth day stigmas predominate. Later, the proportions of florets showing anthers and stigmas become approximately equal. Throughout, the total number of both male and female organs remains low in comparison with the other two strains.

Rongai. No anthers are exserted. Within the first 24 hours from cutting practically no evidence of flowering is seen. After about 5 days stigmas are exserted fairly plentifully, and these increase in number until, by about the fourteenth day, the number of florets with stigmas showing is greater than the total number of florets to be seen in either of the other two strains. This condition persists at least until the end of a month, when the plots have been cut in accordance with the requirements of the yield-experiment.

The yield-experiment was undertaken primarily to determine the behaviour of these three types of Kikuyu grass under a treatment of prolonged close-cutting, and also to relate the yields to varying climatic conditions. This information, it is hoped, will indicate which of the types can best be used under marginal conditions for the grass. The trend of the results already obtained is to show that the Rongai and Molo strains give heavier yields than Kabete, and also that the Molo type is less capable of withstanding frequent defoliation under dry conditions. The greater rapidity of growth of the first two strains may have an influence in retarding the exsertion of anthers, as there appears to be a connexion between anther-exsertion and short herbage, as has already been observed.

The work on the three types of *Pennisetum clandestinum*, from which the observations recorded have resulted, is being conducted at the

[1] From what has already been said, this implies a previous exsertion of stigmas.

Experimental Station at Kabete on the farm of the Veterinary Research Laboratory, where the material obtained from the various areas has been grown. No information is yet available as to the genetical significance of these types, but, as has been explained, they have originated in areas which are spatially and effectively isolated.

Summary

Pennisetum clandestinum occurs in isolated areas at high altitudes in East Africa, where it is the dominant type in a successional phase following the clearance of forest. The natural distribution of the species is extremely limited. The grass is recognized to be of great value for pasture, but its special climatic requirements have hitherto prevented it from being widely used outside the areas in which it occurs naturally and areas of comparable climate.

With a view to the discovery of strains which may be employed over a wider range of conditions, material obtained from a number of different *P. clandestinum* areas has been placed under experiment. Three types have been found, differing in colour and texture of foliage, mode of recovery after cutting, habit of flowering, and ability to withstand frequent defoliation.

The peculiarities of flowering of the species in general are described, and an account is given of differences in flowering between the three types isolated.

Acknowledgement.—It is desired to acknowledge the assistance of officers of the Agricultural Department who obtained material from various parts of the country, and particularly that of Mr. Benstead who provided both the Molo and Rongai types from his district.

REFERENCE

1. D. C. Edwards, Empire J. Expt. Agric., 1935, 3, 153–9.

(*Received September 13, 1937*)

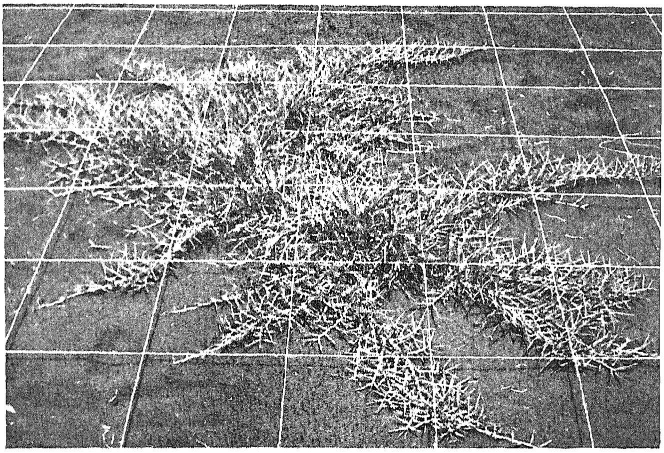

FIG. 1. *Pennisetum clandestinum*, Kabete type

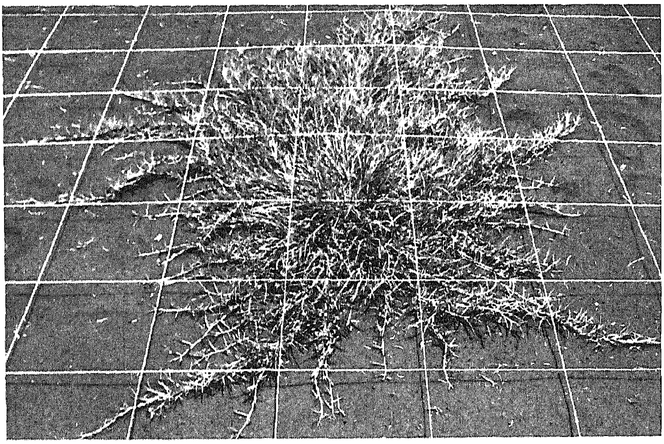

FIG. 2. *Pennisetum clandestinum*, Molo type

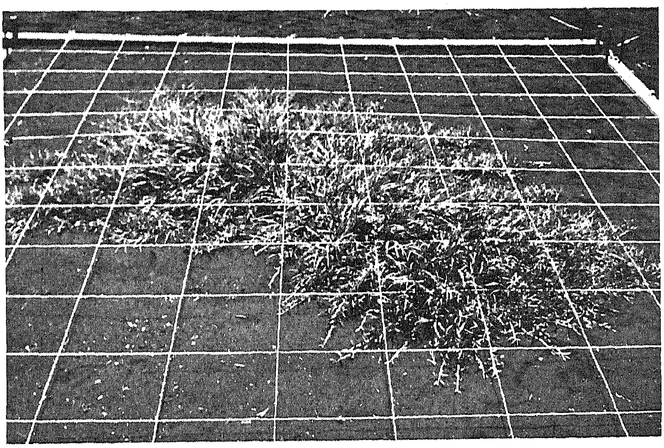

FIG. 3. *Pennisetum clandestinum*, Rongai type

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